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APPLICATIONS

OF THE

SCIENCE OF MECHANICS

TO

PRACTICAL PURPOSES.

BY

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PREFACE.

In the work which is now presented to the public, the author has endeavoured to exhibit in as popular, and, at the same time, as condensed a form as possible, the principles and leading facts of the application of the theory of mechanics to useful purposes. With this view, the nature and mode of action of the prime movers which are employed in the arts, and the engines through whose intervention they are brought into efficient action, have been briefly considered; a selection of useful machines has been introduced, as an illustration of the application of these prime movers; and the machinery used in those manufactures, which have either been successfully introduced into the United States, or promise to be of value to our country, have been cited as practical instances of the manner in which the natural agents have been brought to the aid of human industry.

In treating of these subjects it has been attempted to be as brief as is consistent with an intelligible explanation of them. If, then, it is hoped that the work may not be without its value to practical men, it is not intended to supersede more extensive trea-

tises, or to be a substitute for the knowledge which can be best gained by experience. On all the subjects which have been mentioned, the general popular information which every educated person ought to possess has been kept in view, in preference to the details, which would have swelled the work to an inconvenient size. On the subjects of roads, railroads, canals, and the principles of building and navigating vessels by sails or by steam, a greater degree of extension has been given to the articles. These subjects comprise the great features of internal improvement, and are probably of more general interest than any of those which have been previously named.

A brief sketch of the operations and methods of mining concludes the work. This, it is believed, will be well-timed, in consequence of the attention which is now awakened to the mineral wealth of the United States.

The object which the author had originally in view was the preparation of a text-book for the course of practical mechanics and civil engineering which it is a part of his duty annually to teach. Had he confined himself to this object alone, he would, however, have treated of many of the subjects with even greater brevity. He has, after an experience of nearly twenty years, satisfied himself that the best mode of communicating knowledge of matters of the description here treated of, is by means of a concise text, fully illustrated by geometric dem-

onstrations, analytic investigations, and the exhibition of drawings and working models. With this impression, he invites the attention of the professors of colleges and other teachers of the science of Mechanics to this little treatise, in the belief that they will find in it all that is absolutely necessary to be recollected by the general scholar, and, at the same time, a sufficient basis for the most extensive development of the application of that science to useful purposes.

To facilitate its use for this purpose, he has referred from time to time to his "Elements of Mechanics;" while, for those who have not an opportunity to acquire an accurate knowledge of the theory, similar reference has been made to the "Familiar Illustrations of Mechanics, by Professor Moseley," which forms the 66th volume of Harpers' Common School Library.

Columbia College, 1st February, 1840.

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OUTLINES

OF

PRACTICAL MECHANICS.

I.

INTRODUCTION.

1. MACHINES are defined by writers on the theory of Mechanics as instruments by which the direction or intensity of a force is changed. In elementary treatises they are, in consequence, considered as systems of forces, and in all the variety of their forms may be reduced to a single principle, known as that of virtual velocities.* By this it would appear, that in no machine is there any actual gain; for, whenever the power or intensity of a force is increased by it, the space described in a given time is as much diminished; and, when velocity is gained, the intensity with which the moving force is diminished is in a like proportion.

In proceeding a step farther, we find that in every machine there is a positive loss of the force applied to work it, for its motion is opposed by various resistances, among which friction is the most important.

When we consider machines in their practical application, we find them interposed, like tools, between some natural agent or worker, and a work to be per-

* See Mosely's Illustrations of Mechanics. Renwick's Elements of Mechanics, book ii., chap. vii.

formed, in order to render that work capable of being executed, which would have been difficult or even impossible without the aid of some instrument.

2. Machines are interposed between a natural agent and the work to be performed for several reasons, of which the following are the most frequent and familiar.

(1.) To accommodate the direction which the moving power necessarily has, or that in which it is capable of acting to the greatest advantage, to the direction in which alone the resistance can be overcome. Thus, when a man has a weight to raise to a height, he may, instead of carrying it upward, place a fixed pulley a little above the point to which the weight is to be lifted, and, passing a rope over it, may fasten the weight to it. He may then take hold of the opposite end of the rope, and, pulling downward upon it, draw the weight upward.

(2.) A natural agent may have a fixed and determinate velocity, or it may be capable of working to the greatest advantage at some given velocity, while the work to be performed requires a motion at some other velocity. A machine may therefore be advantageously applied, in this case, to change the velocity of the agent into that best suited for the performance of the work. Thus, as we shall hereafter see, water, falling through some given height, gives to a wheel a certain determinate velocity, at which it will do the greatest possible quantity of work. Such a wheel may be applied to drive the millstones used in grinding grain, and these must have a particular speed, in order to do the work effectually. The intervention of a machine, in this case, is not only convenient, but absolutely necessary.

(3.) A natural agent may be capable of exerting *no more* than a certain degree of force, while it may

be required to overcome a resistance, or remove an obstacle requiring the exertion of a greater force. A machine may, in this case, enable the natural agent to overcome this more intense resistance, or to remove an obstacle which it could not otherwise stir. Thus a single man may wish to lift a stone or other weight, so great that it cannot be moved by his unassisted strength. In this case, by laying a prop on the ground, on which a strong bar of wood or iron is laid, he constructs a machine known under the name of the lever.* By the aid of this he can move a weight which would, without this aid, have required the united strength of several men. But the rate at which the weight is lifted is as much less than that with which he could lift a stone of no greater weight than he could easily have moved, as the weight of the latter is less than that of the former. In this case a work is performed which, to a single man, would have been impossible without the intervention of a machine; or a single man is rendered capable of performing what, without the machine, would have demanded the united strength of several men.

A farther advantage is gained by the use of machines. Without them man is capable of using no other moving force than his own strength, or that of animals used only as beasts of burden; but when machines are employed, he becomes capable of calling to his aid, and employing in the execution of his duties, a number of other natural agents. The most useful of these are the force of wind, of water, and of steam. In the use of these, the duty of the men who have charge of them may become that of superitendence alone.

3. The machines which are used in practical me-

* See Mosely (Harpers' ed.), § 130.

chanics may be either simple or compound. The simple machines are only six in number, viz., the Lever, the Pulley, the Wheel and Axle, the Inclined Plane, the Wedge, and the Screw.* Compound machines are made up of the mechanic powers, combined with each other in various ways, and modified in various manners. In these combinations there is not only a change effected in the direction and in the intensity of the moving forces, but the character of the motion may be changed also.

4. Of the lines which any point of a machine can describe, the simplest are the straight line and the circle. If the point continue to move forward in the same line, the motion is said to be *continuous and rectilineal.* Of this we have no instance in the parts of machines themselves, but it is often found in prime movers.

If the point, after having described a straight line, return along that line to the place whence it first set out, the motion is alternating, and is said to be *reciprocating rectilineal.*

If the point describe an entire circle, turning continually in the same direction, the motion is said to be *continuous circular.*

If the point move through an arc or portion of a circle, and return along that arc to the place of beginning, the alternating motion is said to be *reciprocating circular.*

There may be motions either continuous or reciprocating, in curves other than a circle. It is not, however, necessary that we should distinguish these as a separate class, and they may, in most cases, be considered as performed in circles whose centre is not the same as the fixed point around which the motion is performed. Motions of this character are

* *Renwick's Elements of Mechanics*, book iii., chap. vi.

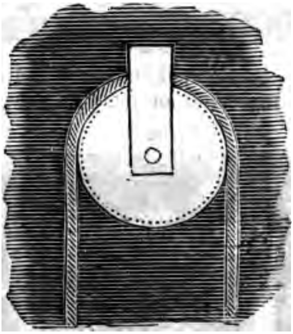
distinguished by the name of *eccentric*, and when continuous they are called *rotatory*, or, in its more usual, but less correct form, *rotary*.

5. Among these four kinds of motions, taken by pairs, ten possible combinations exist; but two of these never occur in practice. Machines have therefore been divided into eight series, viz.:

(1.) Those in which a continuous rectilineal motion is converted into another of the same description, but different in direction.

Instance a simple fixed pulley, Fig. 1. In this a

Fig. 1.

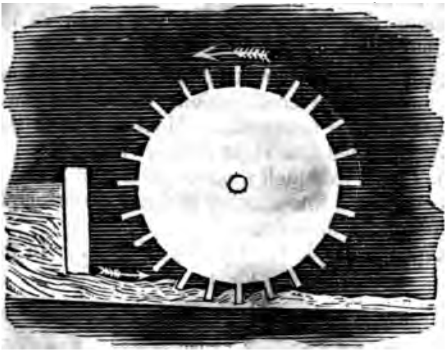


weight, attached to one end of the rope, is drawn upward in a straight line by a force which draws the opposite end of the rope downward.

(2.) Those in which a continuous rectilineal motion may be converted into one continuous and circular, or in which a continuous circular is converted into a continuous rectilineal motion.

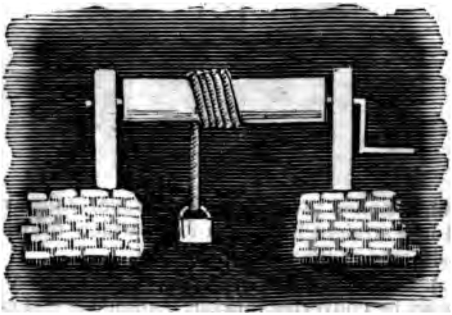
Thus, in the water-wheel, Fig. 2, the stream, running along a straight channel, strikes against the paddles, and gives the wheel a constant motion in

Fig. 2.



the same direction; and in the well-digger's windlass, Fig. 3, the force of men applied to handles

Fig. 3.

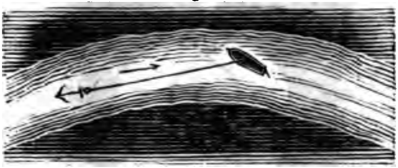


turns the axle of the windlass, and the hands of the men describe a circle, while the weight fastened to the rope is drawn upward in a straight line.

(3.) Those in which a continuous rectilineal motion is converted into a reciprocating circular mo-

tion. For the illustration of this case we shall cite the method used in crossing rivers, known under the name of the flying-bridge.

Fig. 4.

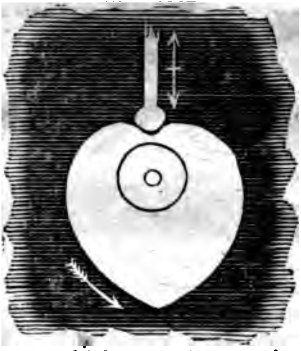


In this a rope is fastened at some distance above the point where the crossing is to be effected, and is attached to the ferry-boat at some distance from its stem. The rope being over a support on that side of the boat which is opposed to the current, the joint effect of the tension of the rope and the force of the stream is to drive the boat across the stream in a circular arc, of which the point to which the boat is fastened is the centre. By changing the position of the rope to the opposite side of the bow, a return to the bank, whence the boat was at first caused to depart, is effected.

(4.) Those in which a continuous circular is converted into a reciprocating rectilineal motion; or a reciprocating rectilineal motion into one continuous and circular. Thus, in the apparatus represented by Fig. 5, an eccentric plate being made to revolve on a fixed axis, will cause a rod which rests upon it to rise and fall alternately. The plate may be circular or of any other figure; where it has such a shape as is represented in the figure, it is called a heart-wheel.

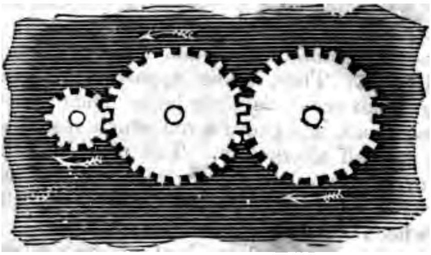
In the piston rod and crank of a horizontal steam-engine, the rectilineal reciprocating motion of the former gives a continuous circular motion to the latter.

Fig. 5.



(5.) Those in which a continuous circular motion generates another motion of the same description. For instance, a tight band may be passed over two wheels at some distance from each other, and if one of them be set in motion, the friction between it and the band will set the band in motion, and its friction on the other wheel will move that wheel also. So

Fig. 6.

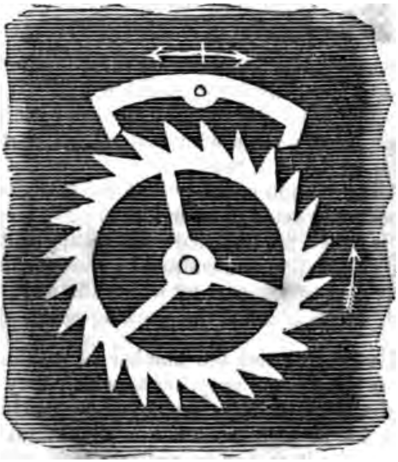


also if teeth be cut on the circumference of a wheel, and these catch into the spaces between teeth cut

upon another wheel, as in Fig. 6, the motion of either of them around its centre will give motion to the other, but in an opposite direction.

(6.) Those in which a continuous circular is converted into a reciprocating circular motion, and *vice versa*. Thus, in the scapement of the common watch, a wheel, called a crown wheel, which is caused to revolve continually by the action of the mainspring, gives a reciprocating circular motion to the verge, which forms the axle of the balance; in the scapement, represented Fig. 7, the revolution of the swing-wheel of a clock gives motion to the an-

Fig. 7.



chor pallets, which are attached to the crotch in which the pendulum is inserted; and thus, in the spinning-wheel, the foot applied to a treadle gives a motion to and fro in a circular arc, and this motion

veyed by a rod to the crank, causes it to revolve continuously in one direction.

(7.) Those in which a rectilineal motion is converted into an alternating circular motion, or a reciprocating circular into a reciprocating rectilineal motion. We have an instance of the first description in the piston-rod and working-beam of the usual form of steam-engine; and of the second in the handle or brake of the common pump.

(8.) An alternating circular motion may be converted into another of the same description, but contrary in direction. Thus a segment of a circle which has a reciprocating motion may be cut into teeth, which catch into the spaces between teeth formed in the segment of another circle.

6. In every machine there are three motions which require to be particularly considered:

(1.) The motion of the moving power itself, which may not be the same with that of the part of the machine on which it acts.

(2.) The motion of the part of the machine which is immediately acted upon by the moving power, and which is called the impelled point of the machine.

(3.) The motion transmitted by the machine, particularly that of the part by which the work is performed, which is called the working point.

7. However great the number of machines, and however various the purposes to which they are applied, the prime movers employed by mechanicians are but few in number, and are all natural agents. The utmost which human art can do is to call into action forces which exist in a latent state, and to direct and control their action. Of the natural agents which are employed in practical mechanics, the most important are:

(1.) The force of gravity, acting through the intervention of some descending weight.

(2.) The elasticity of springs.

(3.) The strength of men and animals.

(4.) Water.

(5.) Wind.

(6.) The force of the elastic vapour of water or steam.

In addition, we use in a few instances the explosive energy of gunpowder. The attractions of electricity, magnetism, and chemical affinity are also capable of setting bodies in motion, and might therefore be applied to drive machines. But the sphere of action of these forces is so limited as to render it improbable that they can ever be applied to any useful purpose, with the exception of the electro-magnetic influence. Of this an application has recently been made which may possibly be effectual. The alternate expansion and contraction of the air by heat has been applied to work mere models, but there are important difficulties in the way of its application on the large scale. We shall have occasion, likewise, to refer to a machine in which the action of heat upon air causes motion.

Among the prime movers which have been proposed, but have not yet been brought into use, is carbonic acid condensed into the solid or liquid form.

There is also in the continually varying pressure of the atmosphere a source of power which might be applied in some few instances, and it has been used for winding up clocks.

Before machines were invented, or while only those of the simpler descriptions were known, man could apply no other prime mover than his own strength. The introduction and improvement of *complex machines* has enabled him to call into his

service the great natural agents, water, wind, and steam.

8. As no motion can take place without the application of an adequate force, so no machine can act unless driven by some natural agent. Neither can any machine long continue to work after the prime mover ceases to act. Hence machines which shall keep up their own action, and which have been sought under the names of perpetual motions, are impossible.

9. The action of a prime mover depends not only on its own energy or intensity, but on the velocity with which it tends to cause the impelled point of a machine to move. The product of these two quantities is called momentum. The work done is also to be estimated by the quantity of resistance overcome in a given time, or by the momentum of the resistance.

Under the term resistance are included not only the useful work performed, but also friction and all other retarding forces, such as the action of gravity, the resistance of the air or other medium in which the motion is performed.

10. When the momentum of the prime mover exceeds that of the resistance, the machine is set in motion, and will move from a state of rest with accelerated velocity. If the prime mover be an attractive force, which acts with equal intensity upon a body whether it be at rest or in motion, the tendency to acceleration will continue. But if, as is more usually the case, the prime mover act more forcibly upon bodies at rest than upon bodies in motion, the rate at which the impelled point of the machine is accelerated will diminish at each increase *of its velocity.* This diminution in the action of the

accelerating force will continue until the momentum of the resistance becomes equal to that of the prime mover. The motion of the machine then becomes uniform, or will vary only within certain limits. It is said to be in a state of permanent working, and equilibrium exists among the moving and resisting forces.

This species of equilibrium which occurs in the motion of a machine is called *dynamical.*

11. When the prime mover is of such a nature as to act more forcibly upon a body at rest than upon a body in motion, a machine impelled by it may cease to do work from two causes: it may be loaded with such a resistance that it can no longer move; or it may move so fast as to receive no new impulse from the prime mover. Between these two states there will be a velocity of the impelled point, with which the greatest possible quantity of work will be performed. This most advantageous velocity of the impelled point is, in most cases, one third of the greatest velocity of which the prime mover is capable; and the resistance which will be overcome at this velocity is four ninths of that which will stop the motion of the machine altogether.

12. It is, in most cases, important that the work of a machine shall be done with a motion of the utmost regularity. A tendency to irregularity may arise from two causes:

(1.) The prime mover may act unequally upon the impelled point of the machine, and yet vary within certain definite limits.

(2.) The prime mover may have a tendency to increase or diminish in its mean intensity and velocity, or the resistance may be subject to variation.

Each of these cases has its appropriate remedy.

The first cause of irregularity may be counteracted by a fly-wheel, the second by a governor.

13. A fly-wheel is a heavy circular disk, usually of metal, to which a great velocity is given by the action of the prime mover transmitted through the machine. This wheel, like all other bodies, is possessed of inertia, by which it resists the action of forces tending to accelerate it, and tends to continue in motion when the action of the accelerating force ceases to act. When, therefore, the action of the prime mover is more than equal to the resistance, the fly-wheel opposes its inertia, but still gradually acquires an increased velocity and corresponding momentum. When the action of the accelerating force diminishes, or even ceases altogether, the fly-wheel does not at once lose its velocity, but parts with it gradually, distributing through the other parts of the machine the excess of momentum it had previously acquired.

Although a fly requires a part of the moving force to set it in motion, and thus, in fact, adds to the resistance, it notwithstanding frequently enables an irregular force to do work that it would otherwise be incapable of performing. Thus, although a man is capable of exerting a force equivalent to raising seventy pounds, yet, when he turns a winch or crank, there is a part of the revolution when his utmost force will balance no more than twenty-five pounds. If, then, the resistance exceed the latter quantity, he will not be able to make the crank perform an entire revolution, and, consequently, can do no work at all. If, however, a fly be applied to the crank, he will be capable of working throughout its whole revolution with a force equivalent to the raising of a weight of thirty pounds.

The effect of a fly-wheel is proportioned to its weight, its diameter, and its velocity.

14. Some engines require no separate fly-wheel, as they themselves, or some of their working parts, may act in the manner of a fly. This is the case in the water-wheel, which will regulate its own motion and that of the machinery it drives. The principle which is employed in the fly-wheel is also used for the purpose of accumulating the force derived from a long succession of impulses, and discharging it at once upon a given object.

The most familiar instance of this application of the principle is to be found in the coining engine. This is a screw-press, worked by a long lever, the two extremities of which are loaded with heavy weights. A rapid motion is given to this lever by the power of men, who abandon it a short time before the die is carried down to the coin. At the instant the die strikes the coin, the whole of the force which has been communicated to the weight is discharged, and thus a deep impression is produced.

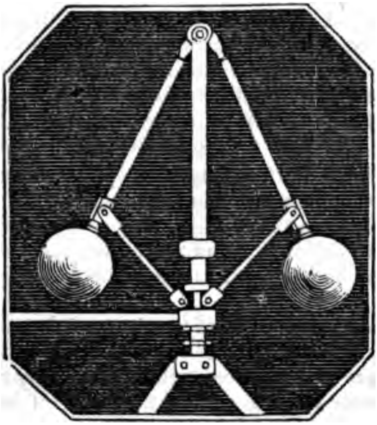
15. When the intensity of the prime mover is subject to variations which are not confined within fixed limits, or when the machine may be required to perform very different quantities of work, the action of the prime mover itself is regulated by an apparatus called a governor.

A governor consists of two heavy balls, suspended by means of bars from a vertical axis. Each of these bars is connected with the axis by a hinge. These bars form a part of a system of levers, by which a collar may be made to move upon the vertical axis. This axis derives motion from the machine, by which a centrifugal force is communicated to the balls. This centrifugal force may acquire such intensity as to overcome the gravity of the balls. They will, in consequence, move outward, and thus *communicate* motion, through the system of levers,

to the collar upon the axis. When the velocity diminishes, the balls fall inward, and thus move the collar in an opposite direction. The collar acts upon an apparatus by which the intensity of the prime mover may be varied. Thus, in water-wheels, it opens or closes the shuttle by which water is admit. to the wheel; in steam-engines, it works a valve by which the area of the steam-pipe is increased or diminished.

One of the forms which the governor frequently assumes is represented beneath.

Fig. 8.



A natural agent which has a tendency to accelerate the machine on which it acts, may notwithstanding be made to give a regular motion, after the acceleration has gone to a certain extent. This is done by calling into action a resistance which increases in intensity in a higher ratio than the velocity of the

part of the machine on which it acts. Such a resistance, it is demonstrated in the theory of mechanics, will finally render any motion under the action of a constant accelerating force constant.

II.

OF PRIME MOVERS.

1. *Of Weights.*

16. A weight may be made to give motion to a machine, by attaching it to a cord, which cord may pass over a wheel or be coiled upon a barrel. As the descent of a weight thus employed has a continual tendency to acceleration, it is necessary that it should be regulated. A regulator adapted to this purpose may be formed by placing leaves or plates of metal in the direction of radii upon a horizontal fly-wheel. As the resistance of the air in which the fly-wheel moves increases nearly in the ratio of the square of the velocity, the resistance to the motion of the leaves finally becomes so great as to counteract any farther tendency to acceleration.

This apparatus does not furnish a perfect regulator, inasmuch as the density of the air is continually varying.

A better mode of regulating the motion of a descending weight is to be found in the pendulum.

A machine impelled by a weight and regulated by a pendulum is called a clock. Its structure will be explained in the proper place.

Wherever absolute accuracy in the rate of the *motion is not required*, the fly-wheel with leaves will

act as a sufficient regulator to the force of a descending weight. Its most familiar application is in the common kitchen-jack, which is an exact model of the form in which clocks were originally constructed. An application of the same principle on a large scale has been made to counteract the tendency to acceleration of cars upon the inclined plane of a railway. There is an instance of this sort on the railroad of the Delaware and Hudson Canal Co.

2. *Of Springs.*

17. A spring is a flat plate of steel, which, if bent from the position which is determined by its original structure, tends to return to its primitive form. The form in which springs are usually fashioned is that of a spiral coil, and such springs are usually enclosed in a cylinder or barrel. This barrel is adjusted around a fixed pin, to which the inner end of the spiral is attached; the opposite end is fastened to the barrel. The spring may be wound up, or caused to form an increased number of revolutions around the central pin, by turning the barrel. As soon as the force by which the spring is wound up is withdrawn, the spring tends to uncoil itself, and, in doing so, turns the barrel around.

The force with which a spring tends to uncoil itself is not constant, but is greatest at first, and gradually diminishes, until the spring is uncoiled. If the spring were of equal elasticity throughout, its force would be always exactly proportioned to its distance from a state of rest. The most frequent application of the spring to drive machinery is in the case of the watch and chronometer.

The arrangement of the spring and barrel will be understood from Fig. 9.

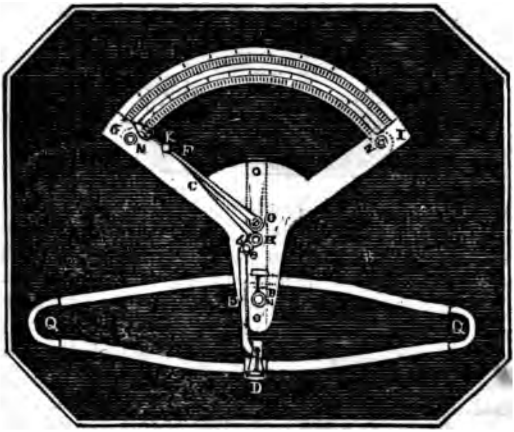
Springs are not only employed for the purpose of

Fig. 9.

giving motion to machines, but also in instruments for measuring the intensity of forces. From the property which has been stated, it will be obvious that an uncoiled spring will yield to the action of a force, until the gradually increasing tension is in exact equilibrium with the intensity of that force. An instrument intended for this purpose is called a dynamometer. The dynamometer of Regnier is composed of two springs, D E, Fig. 10, having each the shape of a circular arc, and which are united together by welding to them two half rings of steel, Q Q, in such manner that the whole has the shape of an oval. From the middle of one of the arcs, a graduated quadrant, N N, projects, which is fastened to the spring at B by a screw. The quadrant is divided so that each division shall represent a determinate weight acting upon a screw. The moveable index, O F K, is acted upon by a bent lever, E H C, the fulcrum of which is close to the centre of the quadrant, and which is attached to the middle of the arc D, opposite to that on which the quadrant is fixed. The apparatus being so adjusted that the index shall stand at *o* when the spring is not acted upon, weig[illegible]

are suspended from it, and the positions into which the index is brought by them marked on the limb, opposite to which the quantity of weight required to bring it into that position is marked.

Fig. 10.



An eprouvette for measuring the force of gunpowder by the tension of a spring has also been invented. This instrument has the form of a graduated quadrant. At one end of the quadrant a small cup is fastened, in which the gunpowder is placed and inflamed. This cup is closed by a flat plate of iron, which is pressed against its opening by a spring. The plate yields to the explosive action of the gunpowder, and the distance to which it recedes along the arc is the measure of the force.

Instruments constructed on similar principles are used to measure the strength of the fibres of flax and hemp, and of the threads spun from cotton and wool.

3. *Of the Strength of Men and Animals.*

18. Animals may themselves be considered as machines, planned by the Creator with consummate wisdom, and admirably adapted to the several states and circumstances in which they are destined to exist.

19. The prime mover in animals is their life, a force whose origin and action are to us inscrutable. This vital energy is made, by the exercise of the will or volition, to act in producing every variety of motion of which the animal is capable; but the manner in which this volition is transmitted is also beyond the reach of our finite capacities. In obedience to the will, the muscles contract or are allowed to lengthen, and the contractile force is applied to cause rigid parts of the animal frame to turn upon the joints. In vertebrated animals, the muscles enclose the rigid parts, which are called bones. In articulated animals, the muscles are enclosed within a jointed shell, to which they give motion.

20. Each several motion of a bone is produced by the joint operation of two muscles, which act in opposition to each other, and are hence called antagonists. One of these acts in its contraction to bend the joint, and is called the flexor muscle; the other tends to straighten the joint, and is called the extensor.

By the united action of two or more pairs of antagonist muscles, and by the simultaneous operation of those which act upon different bones, every variety of position and attitude of which an animal is capable is produced.

The muscles which give motion to the limbs are inserted in the trunk itself, or in limbs

near to the trunk than the parts they are intended to move. These muscles are inserted into the limbs to which they give motion, at no great distance from the joint. Hence each separate bone, when moving around the joint as a fixed point, becomes a lever of the kind ranked by mechanics as the third class. But when the extremity of the limb is pressed against an obstacle, and the muscles act to raise the joint, the arrangement becomes a lever of the second class.

In levers of the third class, velocity is gained at the expense of power. But this loss of power is in no case attended with evil consequences, for the contractile power of the muscles is in all cases adequate to the exigences which the habits of the animal demand. On the other hand, great benefit is derived from the superior degree of agility which is thus conferred, and there are many cases where the mechanical action or useful effect is to be measured by the square of the velocity, instead of by the velocity simply. In all these cases a lever of the third class is required for the most advantageous exertion of the strength of the muscles. The foot of man, on the other hand, is a lever of the second class, and is thus calculated to raise a great weight to a small height by a comparatively small force. The muscles which perform this office are much stronger in proportion than in any other animal, and, accumulated in the calf of the leg, add not a little to the beauty of the human figure. These muscles are wrapped around the heel, which they act to raise by causing the foot to move around its ball as a fulcrum; the weight of the body meanwhile presses on a point intermediate between the insertion of the muscles and the point around which the motion is performed. Man is thus enabled easily to maintain, and move in that erect

posture for which all the rest of his structure is fitted. This posture cannot be assumed by the animals which in other respects approach most nearly to the human structure. In these, the powerful muscles which form the calf of the leg in man are slender and comparatively weak; thus, what in man is a firm support, becomes in them a hand. These animals are hence called quadrumana or four-handed.

21. The erect posture in man is not assumed or maintained without effort. The flexor muscles of the limbs are shorter than the extensors, and thus the position of the joints, when volition ceases, as in sleep or death, is slightly bent. At the instant of dropping asleep, the muscles before in action relax, and if a constrained posture have been assumed in preparing for repose, a sensation is felt similar to that of a fall.

The exertion required to maintain the erect posture is so great, that the muscles which concur in this effort have frequent need of repose; this is obtained by resting the weight unequally on the two feet, and shifting it alternately from one to the other.

22. In most quadrupeds, the relation between the lengths of the flexor and extensor muscles is the same as in man; and thus, when volition ceases, the joints bend, and the position of standing cannot be assumed and maintained without effort. The elephant is an exception to this rule. His great weight would demand a vast exertion of strength to support it, were the usual relation of flexors and extensors preserved. But in this large animal their relative lengths are much more near to equality, and the leg, when volition ceases, takes the form of a straight column. Hence this animal can sleep without lying *down.*

23. Birds have the power of walking upon two feet,)f standing upon but one, even when asleep, and of clinging to a perch during sleep, or even after death. These powers are given by an exactly opposite arrangement to that found in the elephant. The difference in the length of the extensor and flexor muscles of the foot is much greater than in any of the mammalia. In consequence of this, the position of the talons, when the muscles are not exerted, is that of the greatest curvature. In moving the foot, the action of the muscles spreads the toes, and they are set upon the ground in their most extended position. The subsequent repose of the muscles tends to draw the claws together, but this tendency is counteracted by the weight of the bird, and the talons are thus firmly fixed upon the ground, and their position is the more firm the less the will of the bird is exerted. Birds therefore may sleep resting on one or both feet.

In birds which perch when they sleep, the tendons which bend the toes are the prolongations of muscles near the body. These tendons therefore pass over the intervening joint, so that whenever these joints are bent, the tendons are put to the stretch, and close the foot mechanically.

24. In the progressive motion of animals over the ground the useful effect of the muscular force may be resolved into two parts. By the first of these the whole weight of the animal, and, consequently, its centre of gravity, is raised a small distance at each step By the second, the centre of gravity is pressed foı ward until its line of direction falls within a ne base, provided by the forward motion of the limbs.

The first of these motions is performed in m with great ease, in consequence of the mechani *property of the foot* which has been mentioned, ı

the strength of the muscles of the calf of the leg. The second of these motions is performed with the necessary rapidity, because all the other limbs, as we have already stated, are levers of the third class.

25. When a man resting equally on both feet wishes to walk, the body is swayed towards one side until the weight rests wholly upon one of the feet; the other foot is then lifted from the ground, and carried forward until a step of the usual length is taken, and the foot again reaches the ground. While this motion is performing by the foot and leg, the other leg is slightly bent, and the muscles of the calf are applied to raise the centre of gravity to a small height; at the same time, these, with other muscles, are employed to throw the body diagonally forward, until the weight rests upon the foot which has been in motion, and is just set down. The foot which had remained fast during the first step is now raised from the ground, and a similar operation repeated, until it is planted and the weight of the body rests upon it. In running, the foot whence the motion is performed is raised from the ground by a powerful exertion of the muscles, before the other foot is set down. In walking, therefore, both feet are upon the ground together at the beginning and end of each step, and one of them is always resting upon it; while, in running, the feet strike the ground alternately, and the body is, in the interval, thrown into the air.

26. A horse or other quadruped, when about to move, leans forward; his feet are then raised in succession. In walking, one of the fore feet, say the right, is first lifted and thrown forward, the left hind leg is lifted immediately after. A short interval then follows, after which the left fore leg is raised, and almost *immediately* followed by the right hind leg. In

trotting, two diagonally opposite feet are raised at the same instant of time, and, after they reach the ground together, the remaining two feet are raised at the same moment. In racking, where the body is swayed from side to side during the progressive motion, as in the walk of man, the two right feet are raised in quick succession, and are followed, after they reach the ground, by the two left feet.

In galloping, the feet are taken up one by one, but the right fore leg follows the left fore leg at a short interval; the right hind leg moves next, and is immediately followed by the left hind leg.

27. The motion of birds through the air, or flying, is performed by the action of the wings upon the air. These are kept in action by means of powerful muscles situated upon the breast of the bird, and which are hence called *pectoral.* By the action of these powerful muscles a rapid oscillation is given to the wings. Although the velocity of this motion is equal in both directions, yet as the wing is convex above and concave below, it is much more resisted in the downward than in the upward stroke; the result of the two motions, therefore, is to raise the bird. During the downward stroke also, the great feathers which compose the wing strike the air directly, and close upon each other so as to form a continuous surface; while during the upward stroke they meet the air obliquely, or, rather, by an edge, and the air has a free passage between them. The direction of these motions is inclined, and thus the downward stroke is not only efficient in supporting the bird, but in giving it a progressive motion. The breathing apparatus of birds is so constructed that the air they respire is passed through the quills and other tubes of the feathers. By this circulation of air the density of

the bird is materially lessened, and may thus be supported by a less exertion of force.

In the bat, whose skeleton approaches closely in structure to that of man, the wings are membranes spread upon the hind legs and the fingers or toes of the arms or fore legs. Motion is given to the latter of these by strong pectoral muscles, as in birds. In comparing the structure of this animal with that of man, it will be at once seen that the latter has not the power of flying, even with artificial wings, in consequence of a want of strength in the pectoral muscles. We may also see how monstrous and unnatural are the figures intended to represent angels or genii, in which the wings are set upon the shoulders. The flight of birds is directed upward, downward, or horizontally by the feathers of the tail.

The obliquity of the stroke of the wing differs in different birds, and is expressly adapted to their mode of life. It is greatest in birds of prey, which are consequently better formed for horizontal progressive motion, and is least in birds which rise to great heights in a direction nearly vertical.

28. Fish, which live in a denser medium, have bodies whose mean specific gravity is the same as that of the fluid in which they swim. In order to cause their ascent and descent, they are furnished with a bladder filled with air, and acted upon by muscles. When the air-bladder is compressed by these muscles, the fish becomes denser than water, and sinks; when the action of the muscles ceases, the bladder dilates, the fish becomes less dense than the water, and rises.

The air-bladder is situated in the lower part of the body of the fish, thus raising the centre of gravity above that of magnitude; the body, therefore, may be easily overturned. This tendency is counteract-

ed by two fins situated on the breast. These pectoral fins are moved by muscles of little strength, and have little effect in giving progressive motion. For the latter, the tail is the important instrument, by an action resembling that by which a boat is sculled. In this important motion the greater part of the muscular matter of the fish concurs, and the two muscles of each pair are equal in length, so that, under circumstances of rest, the body of the fish remains straight. The tail itself is a large fin, whose curvature is altered by muscles, so that it may strike the water under the circumstances best adapted for progressive motion.

When the volition of the fish ceases, the muscles which are on the air-bladder and the pectoral fins no longer act; the body of the fish, in consequence, becomes lighter than water, and the slightest force overturns it; a dead fish, therefore, rises and floats at the surface belly upward.

The instances which have been cited bear but a small proportion to the vast number which might be adduced to prove design in the animal creation, and the exertion of a consummate wisdom in the Creator. The deepest researches of mechanical science have, at each step of their improvement, manifested more clearly the skill with which the machinery of the animal frame has been planned and adapted to its objects. Still more wonderful is the mode in which the vital energy is made, under the action of the volition, to set the complicated machinery in motion or restore it to rest. This volition, however, has no influence upon those motions which are necessary for the support of the life of the animal. If we rank man highest in the scale of organization, it is not because he is any way better adapted to the cricumstances in which he is intended to live than those animate beings we con-

sider as inferior. When, however, we pass from the grand division of the animal kingdom to which man belongs, we find in animals we are accustomed to consider as inferior, a delicacy and perfection of structure of which even the boasted frame of man falls short.

29. The force of men and animals may be estimated in the weight they are capable of raising through a given height in a given time. Each individual animal will have a different degree of strength, but in those of the same species the comparison may be direct, and the average strength of a number of individuals may be used to express that of each. In comparing the strength of men with that of animals, or the strength of different species with each other, they must be considered as applied to do the same kind of work; and the work which animals are most frequently caused to perform is that of draught. In estimating the force required in this species of work, the animal is supposed to move forward upon a level surface, drawing a cord to which a weight is attached, and that the weight is drawn vertically upward, as might happen in consequence of the cord being passed over a fixed pulley. Man may also be supposed to work in the same manner, and thus their respective strengths may be compared.

30. Animals and men are capable of exerting a great degree of strength when impelled by a sudden impulse, and of moving for a short time with great velocities; but such sudden and violent exertions are followed by fatigue and exhaustion. In estimating the force of animals, it is therefore necessary to take into account the number of hours per day during which an animal can work, without losing the power of recruiting his strength in the intervals of labour.

and the number of days per year for which such work can be performed. The maximum, or greatest speed, then, is to be taken, not as that which can be reached for a short space of time, but as that which can be kept up for the number of working hours in a day; and for the maximum resistance, we are, in like manner, to take that which can be strained against, but not lifted, in working the same number of hours.

The greatest force of draught which a man can exert is taken at 70 lbs., his greatest velocity in walking at six feet per second, or a little more than four miles per hour. By the principle of § 11, a man works to the greatest advantage in draught to raise a weight of $31\frac{1}{3}$d lbs. with a velocity of ten feet per second. This is equivalent to raising 4120 lbs. through the space of one foot in a minute.

The utmost strength of a horse in draught has been estimated at 420 lbs.; his utmost velocity in walking at ten feet per second; he will therefore work to the greatest advantage in draught in raising $186\frac{2}{3}$d lbs., with a velocity of $3\frac{1}{3}$d feet per second. This is equivalent to raising 37,333 lbs. one foot high per minute.

A man may work at his most advantageous speed for ten hours per day, for several successive days; a horse cannot work more than eight; but, in both instances, days of rest must be allowed from time to time, in order to prevent a prostration of strength. One day of rest in every seven is found to be sufficient to restore the strength of animals and men, working against resistances having the foregoing maximum measure, while fewer will not answer the purpose; hence the institution of the Sabbath is one of absolute necessity to the well-being of mankind and the animals it has domesticated.

Taking into view the difference of the number of hours each can advantageously work per day, the

strength of a horse applied to draught is usually estimated as equal to that of seven men.

The strength of a horse is often used under the name of a horse-power, as the unit in which the force of other natural agents is estimated. This unit has been sometimes taken as low as 28,000 lbs., sometimes as high as 44,000 lbs., each supposed to be raised one foot per minute. The estimate of this unit which we shall employ is 33,000 lbs. raised one foot per minute.

31. Draught is by no means the most advantageous mode of exerting human strength; in fact, there is no mode in which he can be applied to that purpose, whereby he can do more than by the mere exertion of the muscles of his arms and hands. But in bearing burdens, the relation between the strength of a man and that of a horse becomes greater than one seventh. The force of the former applied to draught is limited to seventy pounds, while he can move under any weight less than twice his own. Even when loaded with a weight bearing to his own the relation 3 : 4, he can mount almost vertically upward, as upon a ladder, with a speed of two feet per second. A horse, on the other hand, supports less weight than he is capable of drawing, and cannot carry even his own weight up a plane inclined more than 45° to the horizon.

Men may carry weights nearly equal to their maximum force of draught, and move under them with considerable speed. Thus a Roman soldier bore in his arms provisions and equipments, sixty Roman pounds, and performed journeys at the rate of five miles per hour. A French grenadier is loaded with fifty French pounds, and marches at the rate of three miles per hour. The weights which are borne by persons habituated to that species of labour are v

remarkable; the most signal instances of this application of strength are to be found in the porters of Constantinople and Bagdad, the Gallegos of Lisbon, and the coal-heavers of London.

The following facts will illustrate more fully the force exerted by men and horses, applied to different kinds of labour.

A man trained to running will pass through twenty-five feet in a second, or move at the rate of about nineteen miles per hour. A race-horse can run forty feet per second, or at the rate of twenty-seven and a quarter miles per hour; neither of them can sustain such a degree of speed for more than seven or eight minutes.

A man will walk without a load for ten hours per day, and perform a distance of from twenty-five to thirty miles; a horse walks faster, but cannot continue his labour as long; thus the distance performed is about equal, and in the long run a man will outtravel a horse. We have ourselves witnessed the performance of natives of Massachusetts in search of lands, who have for a week together walked forty miles per day, carrying a weight of 15 or 20 lbs.

A man will carry a weight of 140 lbs. on his back with a velocity of one and a half feet per second. If he throw it down and return unloaded for a new burden, he is capable of working six hours per day. Using the French mode of expression, his daily work is represented by the number 702.

A traveller may carry 88 lbs. on his back, with a velocity of two and a half feet per second, for seven hours per day. The expression for the daily work is [illegible].

A horse will carry 265 lbs. at the rate of three and a half feet per second. Working for eight hours per day, the work may be represented by the number

3800, or for 10 hours by 4750. If he trot, the load must be diminished to 177 lbs., but the velocity is doubled, and the time of profitable labour does not exceed seven hours. The number, therefore, is 4435.

A man pushing a handcart, and returning unloaded, will transport 220 lbs. at the rate of one and a half feet per second. The number which represents his performance is 1800. With a wheelbarrow the load is only 133 lbs., and the number 1080.

A horse draws on a cart 2000 lbs. with a velocity of three and a half feet per second for eight hours per day, being a useful effect of 27,000. In trotting he will not draw more than 800 lbs. with a velocity of seven feet, and the duration of his labour is diminished to four and a half hours per day.

A man who walks without a load up a gentle slope or staircase, will raise his own weight vertically upward at the rate of six inches per second. Taking his weight at 144 lbs., and the day's work at eight hours, the number which represents it is 281. In lifting a weight by a cord passing over a pulley, the useful effect is no more than 77; in carrying articles by hand up an inclined plane, it is 73; and if upon the back, no more than 56. It will therefore be seen, that if a man were to raise no more than his own weight, and cause it to act as a counterpoise to the weight intended to be raised, he might perform almost twice as much work as if he used a pulley or bore it in his hands, and nearly three times as much as if he carried it on his back up a ladder.

A man who walks upon steps cut on the circumference of a wheel, acting by his weight upon its horizontal diameter, raises a weight of 133 lbs. at the rate of six inches per second. The useful effect is 259. A man who walks, pushing a resistance before him, as when working upon a capstan, ov

comes a resistance of twenty-seven pounds with a velocity of two feet per second, giving the useful effect 207. In working on a winch, the resistance is 17½ lbs., the velocity two feet and a half per second, the useful effect is 173. In rowing, the useful effect is 275.

A horse working on a capstan raises 100 lbs. at the rate of three feet per second, giving a useful effect of 1166.

It will therefore appear that the most advantageous manner in which human strength has been applied, is in the act of rowing. As this would be applicable with difficulty to the motion of a machine, the next best mode should be employed, which is that of causing them to step upon a wheel immediately above its horizontal diameter.

The numbers which we have used to express the relation of the several useful effects are the units employed by the French writers on these subjects, and denote the number of cubic metres of water raised to the height of one metre in a day. This furnishes a less complicated mode of comparison than had we used the English method, in which the number of pounds raised to the height of one foot is employed.

4. *Of Water.*

32. Water may give a circular motion to a machine in three ways: by its impulse, by its weight, and by its reaction.

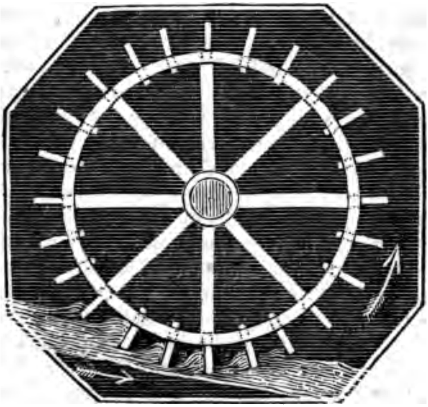
The utmost effect which any stream of water could possibly produce, would be equivalent to raising the weight of the water to the height whence a heavy body would fall in acquiring the velocity of the current. We shall take this for the measure of the mechanical force of the water, and compare with it the *useful effects* produced by the three different methods.

33. The apparatus on which water acts by its impulse to produce a circular motion is called an undershot wheel.

An undershot wheel is suspended upon a horizontal axis, and in its usual form has upon its circumference a number of floats or paddles, whose planes pass through the axis, and which dip, in the lower part of their revolution, into a current of water. These paddles are usually known by the name of buckets.

This form is represented beneath.

Fig. 11.



34. An undershot wheel may be loaded with such a weight as will prevent it from turning, or, were there no resistance, might acquire the whole velocity of the stream; in neither case could it do any work. Its greatest or maximum effect is produced where its velocity is two fifths of that of the stream. This fact was first discovered in the experiments of [illegible]

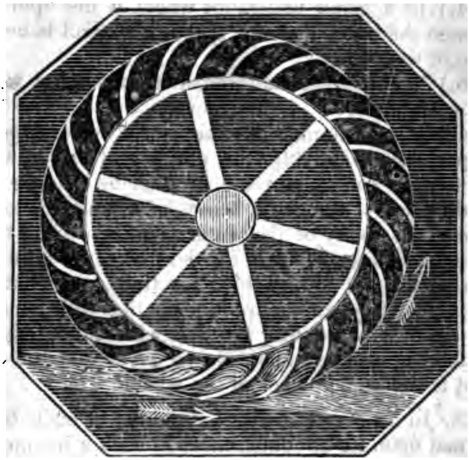
ton, and has since been shown to be consistent with theory. It is also inferred from theory, that at this velocity of two fifths, the useful effect of the wheel would be, to raise one third of the weight of the water which forms the current to the height whence it must have fallen to acquire its velocity; or, in other words, one third of the mechanical measure of the action of the water. This last inference is found to vary from the truth in different modes of placing the floats upon the wheel.

35. When the action of undershot wheels was first considered scientifically, it was inferred that, in order that the water should act more advantageously, no float should interfere with the flow of the current upon another. To fulfil this condition, when the lower float is vertical, the preceding float should be just quitting, and the succeeding float just entering the water. Constructed in conformity with this condition, the best effect was found to be little more than one fourth of the mechanical measure of the action of the water. Smeaton, in his experiments, found that the most advantageous position of the floats was such, that when one bucket was vertical, two others should be immersed in the water, a fourth entering, and a fifth emerging from it. In the former case no more than two floats can be in the water at the same time; in the last case there may be four. With the latter construction the effect of the wheel becomes three tenths of the mechanical measure of the action of the water.

36. A farther increase in useful effect may be gained by closing up the face of the wheel, and applying flaunches or edges to the two vertical sides of the float; the useful effect then becomes $\frac{36}{100}$ths of the mechanical measure of the action of the water.

37. A still better arrangement is that propose by Poncelet, and represented beneath.

Fig. 12.



In this wheel the floats, instead of being plane su: faces, are curved into the form of a portion of cylinder. By this arrangement the force of a undershot wheel has been doubled, or increased t two thirds of the mechanical measure of the actio of the water.

The following are the laws which govern the ac tion of undershot wheels.

(1.) In a given undershot wheel, if the velocity o the stream be given, the useful effect is as the quan tity of water expended.

(2.) In a given undershot wheel, if the quantity o water expended be given, the useful effect is as th square of the velocity.

(3.) In a given undershot wheel, if the quantity of water expended be given, the effect is as the head of water.

(4.) In a given undershot wheel, if the aperture whence the water flows be given, the effect is as the cube of the velocity.

(5.) To estimate the force of an undershot wheel in horse powers:

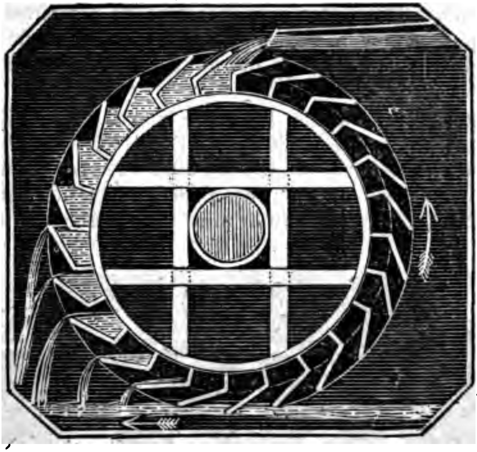
Multiply the number of cubic feet of water expended per minute by 62½ (the number of lbs. in a cubic foot of water), and the product by the effective head or height whence a heavy body must fall to acquire the velocity of the water. This product must be reduced to one fourth for the first form of the undershot wheel; to one third for that on Smeaton's plan; to thirty-six hundredths for that with flaunches; and to two thirds for that with curved floats. Divide the product thus reduced by 33,000, the quotient is the horse power of the wheel.

38. In an overshot wheel a number of buckets are formed upon its circumference, in such a manner as to receive water at the highest point of their revolution, and discharge it wholly at the lowest. One half of the buckets is therefore loaded with water, which, by its weight, causes the wheel to revolve.

This arrangement may be understood by inspection of Fig. 13.

39. In addition to the action of the weight of the water with which half the wheel is loaded, the stream may act by its impulse upon the upper bucket; and it has been attempted to investigate by theory at what relation of height between the wheel and the whole fall, these two modes of action united would produce the greatest useful effect. The inference was, that the height of the wheel should be two

Fig. 13.



thirds of the fall, and that the water should strike with the velocity acquired in falling through the remaining third. Experience has, however, shown that this opinion is fallacious; and it is indeed obvious that these two actions cannot be made to concur usefully, because the velocity which is best suited to the one mode differs from that adapted to the most advantageous performance of the other; and because the succession of impulses which is given to the buckets is inconsistent with the steady motion produced by the weight.

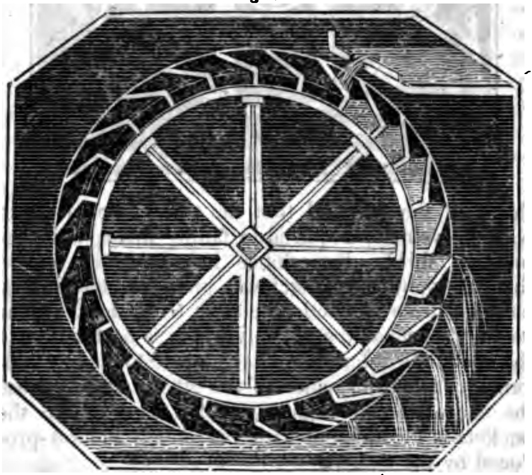
The best practical rule is that the water shall reach the wheel with a velocity little greater than that with which the latter revolves; but the former velocity may be double that of the wheel, without producing any important loss of power.

The velocity which in practice is found to be most *advantageous* for the circumference of a water-wh

is not less than two, nor more than three feet per second. The water may therefore be permitted to drop upon it from the bottom of a spout or flume of not less than four, nor more than fifteen inches in depth.

40. As the water in the upper bucket has no effect in turning the wheel, it is better to make the wheel the whole height of the fall, or even somewhat higher; the water will be then introduced, as in the figure beneath, into the second or third bucket from the top.

Fig. 14.



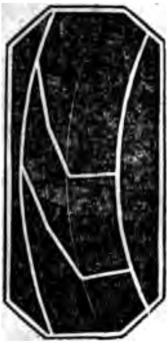
An additional advantage is gained by this arrangement, for, the channel or waste-race, by which the water is carried off, must generally be made in a continuation of the same direction as that in which the water runs towards the top of the wheel. When the water is admitted into the uppermost bucket, the water in the waste-race moves in a direction opposite

to that in which the lower part of the wheel revolves and thus acts as a resistance. But when the water is admitted into the second or third bucket from the top, the direction of the current in the waste-race is the same as that of the revolution of the lower part of the wheel.

41. With the most imperfect form of the overshot wheel, the useful effect is never less than two thirds of the mechanical measure of the force of the fall of water. With the most advantageous construction, it may amount to eight tenths of that measure.

42. The ordinary mode of constructing the buckets of overshot wheels is to close the whole circumference of the wheel by boards called the shrouding. To this are applied, at equal distances, other boards, at right angles to the circumference, which are again met by a third set of boards, forming, with them, an obtuse angle. This arrangement is exhibited in the figure on page 52. The buckets are sometimes made of sheet iron, in which case they are formed into a regular curve.

Fig. 15.

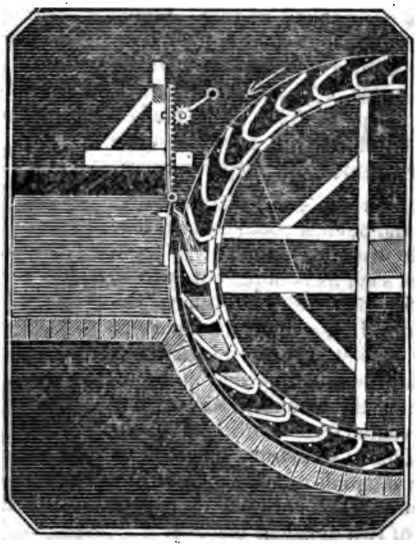


43. It is important that the buckets should be constructed so as to lose as little water as possible; hence a section, such as is here represented, is better than the first we have described. If, however, the aperture of the bucket be made too narrow, the water will be impeded in its entrance by the contained air, or may be prevented from entering altogether. This is sometimes obviated by means of small tubes, which form a communication between the upper parts of two adjacent buckets.

The power of an overshot wheel may be calculated by multiplying together the number of cubic feet of water expended per minute, the height of the fall in feet, and the constant number $62\frac{1}{2}$. Eight tenths of this product divided by 33,000 will give the horse power in the most advantageous case, and two thirds of it in the worst form.

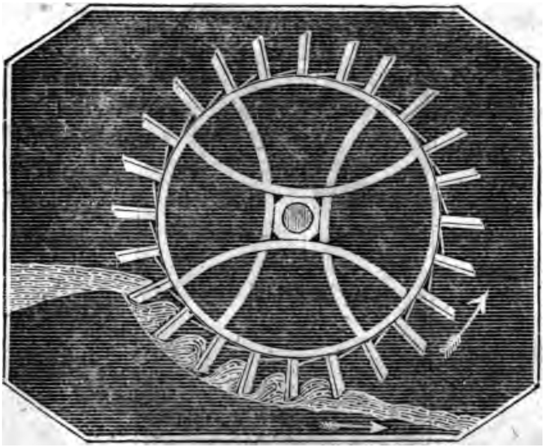
44. When the water is admitted into the bucket which corresponds in position with the horizontal diameter of the wheel, or at a point still lower, the apparatus is called a breast wheel. It may, in the first case, have buckets similar to those of the overshot wheel. When the water is admitted below the hor-

Fig. 16.



izontal diameter, the wheel is enclosed in a channel which it nearly fills, and is furnished with floats, as represented in the annexed figure, instead of buckets.

Fig. 17.

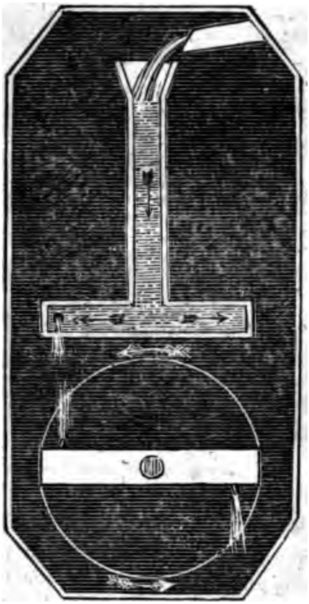


The force of a breast wheel may be calculated in the same manner as that of the overshot wheel of the least advantageous structure.

45. When water is introduced by a pipe into a horizontal box, and openings are made on the two opposite sides of the box near the ends, the pressure being taken off at these openings, that on an area equal to that of the openings, and opposite to them, becomes sensible; and thus there is a tendency to motion in the box, in a direction opposite to that in which the water issues from the openings. If, then, the box be supported in the middle upon a pivot, it will be caused to move in a continuous circle. This motion is said to be d

to *reaction.* This arrangement is represented
neath, and is known by the name of Barker's M
from the person who first proposed its use. Mo

Fig. 18.



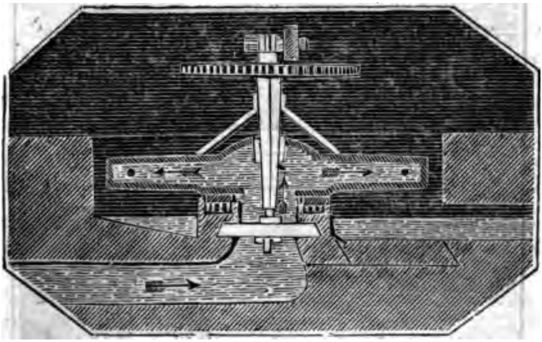
are occasionally constructed of the reacting wheel
which there are three arms instead of two.

It was inferred from theory that Barker's Mill w
the most advantageous possible method of using t
power of water, particularly when a small stream
to be applied, which falls from a great height. I
these anticipations have been far from being realiz

in practice. The cause of this difference is that the pipe, by which the water is admitted, being attached to the revolving apparatus, revolves also, and the water within it acquires a centrifugal force, by which its gravity, and, consequently, its pressure, is diminished.

46. In consequence of this defect, Barker's Mill has been modified by admitting the water from beneath, by an aperture to which the revolving part of the apparatus is adjusted by a water-tight joint. This form of the reacting wheel is represented beneath.

Fig. 19.

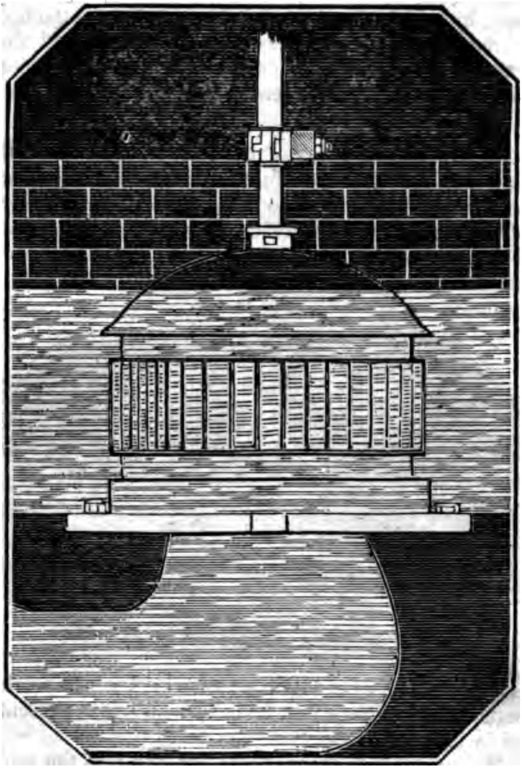


47. A form of reacting water-wheel, which works beneath the surface of a body of water, is represented in Fig. 20.

The water, introduced from beneath into the middle of the wheel, acts upon floats inclined to its radii, and emerges obliquely into the channel which surrounds the wheel.

48. In another form, the water is conveyed by

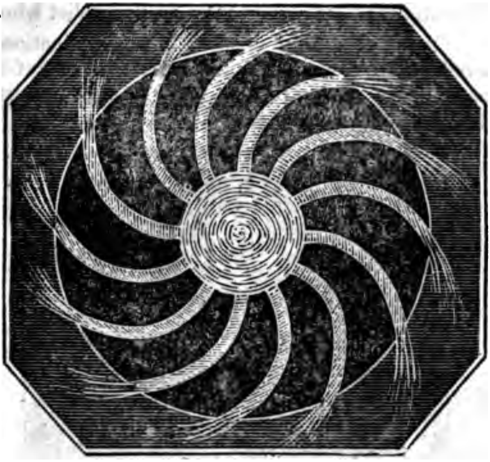
Fig. 20.



the centre of the wheel in a number of spiral grooves to the circumference, whence it issues in the direction of a tangent. (See Fig. 21.)

Innumerable other forms of horizontal water-

Fig. 21.



wheels have been proposed; few or none of them have advantages equal to those of the overshot wheel.

49. The use of the overshot wheel is usually limited to heights less than fifty feet, in consequence of the expense of constructing wheels of great diameter. In cases where the fall is great, the best possible arrangement is that of an endless chain revolving over axles, and to which buckets like those of an overshot wheel are attached.

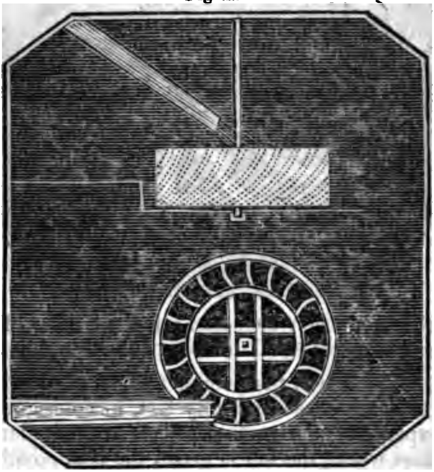
The power of this apparatus may be calculated as in the best form of overshot wheel.

50. A horizontal motion is sometimes produced by the direct impulse of water. The simplest wheel used for this purpose is a low cylinder or drum, on the circumference of which a number of plane leaves

are adjusted in an inclined direction. Such a wheel acts with even less power than an undershot wheel.

51. A better method consists in the application of curved spiral channels to the circumference of the wheel. The power of this form is said nearly to equal the best overshot wheel.

Fig 22.

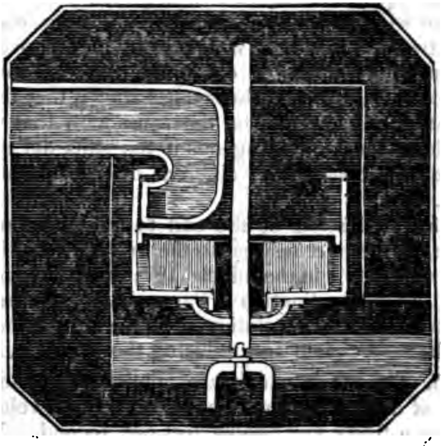


52. The Danaid is an instrument which has recently been introduced in France, for using the force of water conveyed in a pipe. It is formed of a vertical axle, to which are adapted leaves usually eight in number. The axle, with its leaves, is enclosed in a tub having a circular hole in the bottom corresponding in dimensions to the axle. The pipe which conveys the water is bent into the tub, and closed at the end. A vertical slit is made on the side of

the pipe whence the water spouts against the leaves, and the water, after having acted, is discharged by the hole in the bottom of the tub.

A section of this instrument is given in the annexed figure.

Fig. 23.



5. *Of the Wind.*

53. The apparatus by which the wind is made to produce a rotary motion is called a cap windmill.

54. There are two kinds of windmill, the horizontal and the vertical. The parts of the windmill which receive the impulse of the wind are called sails. In the horizontal windmill, the sails revolve in a horizontal direction around a vertical axis. In the vertical windmill, the sails revolve nearly in a vertical plane, around an axis nearly horizontal.

In the latter form, arms, usually four in number,

are attached to the axis, and at right angles to it. To these arms a framework is attached, on which the sails are spread. Were the pieces of wood which form this frame, placed in the same vertical plane with the four arms, the sails would have no other tendency than to overturn the mill. They are, in consequence, inclined to this plane, and the force of the wind is therefore capable of being resolved into two parts, one of which still tends to overturn the mill, the other to cause the arms to revolve. Experience, aided by theory, has shown that this inclination must neither be the same with that which would be most advantageous if the sails did not revolve, nor constant at different distances from the axis.

The inclination of the sail to the plane of the arms, at the part nearest to the axis, is made in the best mills, 22°; in the middle, 18°; at the extremities, 7°. As this inclination is the same, and towards the same direction of revolution, in all the arms of the mill, all the sails concur in producing the rotary motion.

55. The winds which are applicable to the purpose of driving windmills, are such as have velocities between thirty and twelve feet per second. When the velocity falls short of the latter limit, a current of wind is found insufficient to perform any effective work. When this velocity exceeds twenty-five feet per second, it becomes necessary to lessen the surface of the sails, in order to prevent the arms from being broken; and when it exceeds thirty feet, no sail can be safely spread.

It has frequently been attempted to construct horizontal windmills, but they have always disappointed the projectors. In Smeaton's experiments, the effect of the horizontal windmill was not found to be greater than one eighth of the vertical windmill exposing

the same surface of sail. The reason of this is, that in the vertical windmill all the sails concur in the rotary motion, while in the horizontal no more than one sail acts at a time to the greatest advantage, and half the sails are constantly moving in a direction contrary to that of the wind.

The most important application of wind is to propel vessels by its action on their sails. This will be treated of hereafter.

56. The useful effect of a vertical windmill is about equal to a pressure of one pound on each square foot of surface.*

* The laws which govern the action of the windmill are as follows:

The velocity of the sails of a windmill, whether it be loaded so as to produce the maximum effect, or whether it have no load, is proportioned to the velocity of the wind. Within the limits already stated for the useful velocity of the wind, the number of revolutions varies from six to twelve.

The maximum of effect is produced when the velocity with which the extremity of the arms revolves is about the same as that of the wind. When unloaded, therefore, the most distant part of the sails revolves more rapidly than the air moves. The maximum of effect is produced with two thirds of the maximum velocity.

The maximum effect increases in a ratio somewhat less than the square of the velocity of the wind.

In a given windmill, the load corresponding to the maximum effect is nearly as the square of the number of revolutions in a given time.

When a mill is so loaded as to produce the maximum effect with a given velocity, and the velocity of the wind increases while the load remains unchanged, the increase in the quantity of work is, for small changes of velocity, as the squares of the velocity; when the velocity of the wind is doubled, the effects are increased in the ratio 10 : 27½; when the increase in the velocity is more than 2 : 1, the effects are increased only with the velocity of the wind.

When the sails of different windmills are similar in number and position, the number of revolutions in a given time is inversely proportioned to the length of the arms.

The useful effect of similar windmills is proportioned to the squares *of the length* of their respective arms.

6. *Steam.*

57. Water boiling in an open vessel reaches a temperature of 212°, and forms steam of the same temperature with itself. The steam thus formed has a bulk 1694 times as great as that of the water which is evaporated to form it, and an elastic force or tension equivalent to the pressure of the atmosphere. This pressure is estimated at fifteen pounds on every square inch of surface exposed to it.

When water is confined in a close vessel, it may acquire a much higher temperature, and the steam which is formed has the increased temperature of the water. With the elevation of the temperature, the tension of the steam increases, but in a higher ratio. The relation between the temperature and the tension of steam is a complex one, but it is sufficient for our purpose to state that the tension doubles very nearly for every increase in temperature of 40°. Thus steam of the temperature of 252° has a tension of about two atmospheres; steam of 292°, a tension of about four atmospheres.

58. When the tension of steam exceeds three atmospheres, or when it is capable of acting against the pressure of the atmosphere with a force of thirty pounds per square inch, it is called high steam. The density of high steam is greater than that of low steam, but does not increase as rapidly as the tension. For example, while the volume of steam of one atmosphere is, as we have stated, 1694, that of steam of two atmospheres is 909, of three atmospheres 625, and of four 476; instead of 1694 : 847 : 423½, which these volumes would have been had the density increased as rapidly as the tension.

59. Steam is generated for the purpose of being applied as a prime mover, in close vessels called

boilers. The only materials of which boilers hav ever been made are cast iron, wrought iron, an copper. The two latter are formed into sheets, an boilers are constructed by riveting them togethe Of these materials, cast iron is the cheapest, an copper the most costly; cast iron possesses the leas and wrought iron the greatest strength. Copper not acted upon by the air, and is not so readily acte upon by substances held in solution in the water, a iron. When the boiler is worn out, the cast iron nearly worthless, wrought iron of little value, but i copper there is no other loss than the workmanshi and a small diminution of weight. The strength o copper is greatest when it is cold, and is perceptibl diminished even at the temperatures used in genera ting steam. The strength of wrought iron increase up to temperatures beyond those at which steam usually employed.

With proper precautions, wrought iron may b made to endure for a long time, and, in consequenc of its comparative cheapness and superior strengt has almost wholly superseded the two other material

60. The principal cause of the rapid wear whic sometimes destroys boilers, is to be found in th solid matter which is conveyed into them along wit the water with which they are supplied. This soli matter may be either in the form of mud and san mechanically mixed with the water, or in solutio The water of rivers at a distance from the sea con tains only the former kind of impurity; and as it continually injected with the water, while none of is carried off by the steam, it will finally collect i the form of a crust on the lower parts of the inne surface of the boiler, unless some means be taken t prevent this deposite. Wherever such a crust formed upon a part of the boiler exposed to heat

will protect the metal of the boiler from the cooling effect of the water it contains; the part beneath it, if in contact with air and flame, will often burn. This is more particularly the case in a wrought-iron boiler.

When a boiler is supplied with sea water, a period will arrive in its use, if proper precautions be not taken, when the double sulphate of lime and soda will begin to be deposited. Common salt will next cease to be held in solution. The crust thus formed will not differ in its effects from the mechanical deposite. Finally, the muriates of lime and magnesia will begin to be deposited. These last-named substances are capable of being decomposed by the metals, which are corroded in the action, and their effect on copper is almost as certain as upon iron. In order to prevent danger from the deposite of the last-mentioned substances, it has been usual to suspend the action of a boiler fed with salt water for a day in each week, in order that it might be cleansed and scraped out. It is possible, however, by permitting water to flow from the bottom of the boiler from time to time, under the pressure of the steam, to prevent or remove these deposites.

Even when clear spring water is used, a small quantity of saline matter, usually sulphate of lime, is often present, and, although it may be long before any deposite takes place, still it becomes necessary to guard against any injury to the boiler growing out of this cause. For this purpose, it is sufficient to put into the boiler clay, gum, or some cheap substance which contains starch, and any injurious deposite from ordinary hard water may be prevented for several months.

61. The strength of boilers to resist explosive action *depends upon* the tenacity of the material, the *thickness of the* plates of which they are composed,

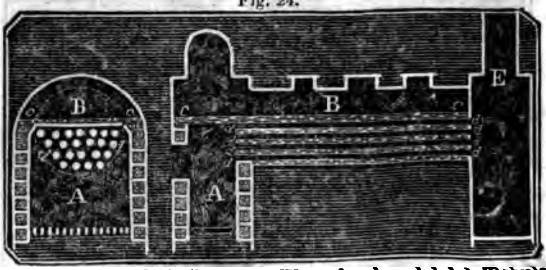
their figure, and the dimensions of their section. Wrought iron, as has been seen, is the most tenacious material, and its tenacity increases with the heat.

In boilers of similar figures, the thickness of the plates of which they are composed requires to be increased in the ratio of the squares of their lineal dimensions. Of all practicable figures, the cylinder is the strongest, and ought, if circumstances will permit, to be employed wherever high steam is generated.

The diameter of a cylindrical boiler ought not to be less than 18 inches, otherwise it becomes difficult to cleanse; and must not be greater than five feet, or it would be impossible to give it a proper degree of strength to resist an explosive action from within.

62. Upon the land, plain cylindrical boilers set in masonry are to be preferred. In steamboats and for locomotion, the boiler must contain a chamber for the fireplace, and be furnished with internal flues, for the purpose of using all the heat which can be afforded by the combustion of the fuel. Of all boilers yet brought into use for these purposes, that employed in many recent locomotive engines is to be preferred. This form is represented beneath.

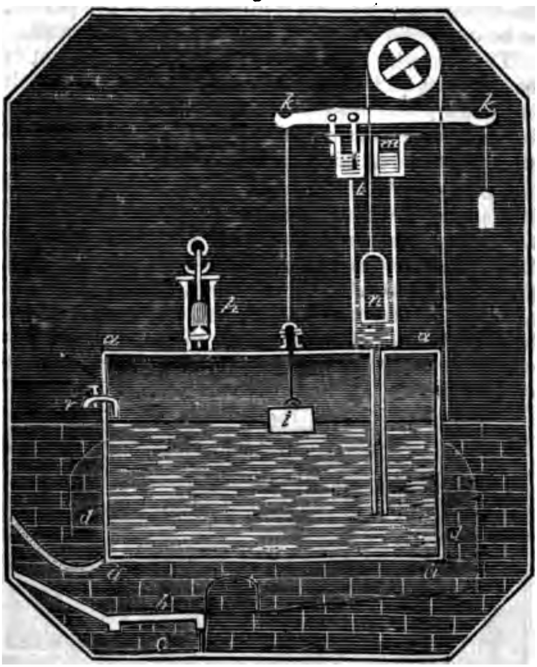
Fig. 24.



A. Furnace. B. Boiler. c c. Water level. d d d d. Tubular flues. E. Chimney.

The forms of which boilers have been made are so various, that it would occupy too much space to enter into the consideration of their relative advantages and defects. Among those most worthy of notice are the original boiler of Watt and the boiler for steamboats. A longitudinal section of the boiler of Watt is exhibited beneath.

Fig. 25.



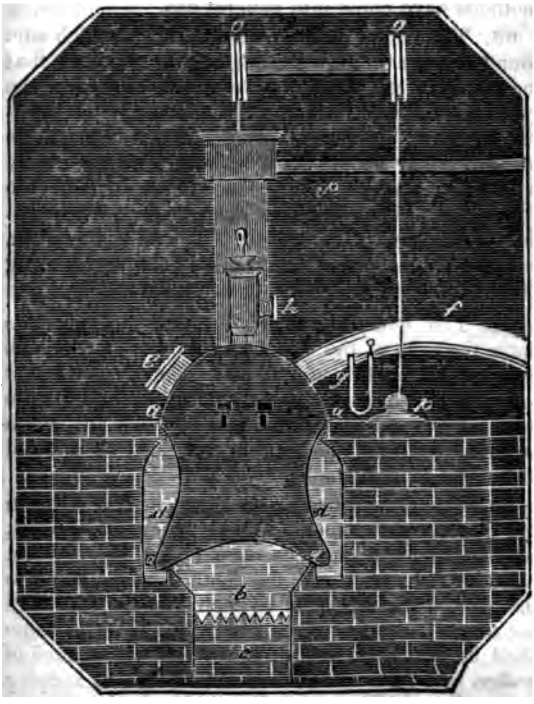
a a a a. Boiler.
b. Furnace and grate bars.
c. Ash-pit.
d d. Flue.

h. Safety-valve.
i. Float of feeding apparatus.
k k. Lever of do.
l. Valve of feeding apparatus.
m. Cistern of do.
r. Counterpoise of damper.

Fig. 26 is a cross section of the same boiler, in which the same letters indicate the same parts as in fig. 25. In addition,

f. Represents the steampipe.
g. Steam gauge.
e. Man-hole.
p. Self-acting damper.

Fig. 26.



As a substitute for boilers, it has been attempted to generate steam in other ways. Thus: water has been flashed into a red-hot vessel, as in the apparatus of Babcock; it has been heated intensely in a strong vessel, as in the generator of Perkins; and the flame and heated air of the furnace have been admitted into the boiler, to aid the steam in its action on the engine, as in the boiler of Bennett. None of these methods have come into general use.

63. The length of the horizontal flues which surround or pass through boilers, ought to be such that the whole of the flame may be expended before the gases proceeding from the furnace reach the vertical chimney. If shorter than this, much heat will be wasted. Nor should they be much longer, otherwise the air which enters the chimney will be too cool to maintain a sufficient draught for the combustion of the fuel. The length of the flues, therefore, depends upon the description of fuel employed, being greatest in such as burn with much flame.

64. The quantity of steam generated depends upon the area of the surface of the boiler which is exposed to the fire and flame. Eight square feet are sufficient to generate the steam required for the nominal unit called a horse power, when low steam is generated, and nine square feet must be allowed in the use of high steam.

65. The dimensions of the furnaces depend upon the quality of the fuel. Wood, being least dense, requires that the furnaces should have the greatest capacity. In respect to the depth from the boiler to the grate bars, this must be such that the fuel shall not touch the metal of the boiler, and that the flame shall be developed before it touches the surface of the flue. All the attempts at saving heat by keeping

a large surface of metal in close contact with the fuel have failed, as has the method of injecting water into heated tubes.

Boilers are liable to dangers of various kinds, and for each there ought to be not only a self-acting mode of relief, but also an indicator of the approach of the danger.

66. A regular supply of water is not only necessary to the constant action of the engine, but is also of vast importance to the safety of the boiler itself.

Indeed, the most frequent cause to which the explosion of boilers can be traced, is a deficiency in the water they contain. In this case a part of the metallic surface which is in contact with the flame may become dry. When this happens, the boiler, if of iron, may become capable of decomposing water and its vapour; and to this generation of gas fatal explosions have been occasionally attributed. It seems, however, doubtful whether this decomposition can take place to such an extent as to be often productive of serious danger. A much more probable explanation is to be found in the relation between the density of steam and its temperature. Steam, after it is generated, may have its temperature raised by the contact of heated metal. It will now be under circumstances approaching to those which occur when it is heated out of contact with water, and, instead of becoming denser with the increased temperature, will become rarer and less capable of working the engine, unless that also have a high temperature. If, however, water, itself heated, although to a less temperature than the steam, be injected into the space occupied by the steam, the temperature of the latter will be but little lowered, and the steam will at once assume the density and explosive energy belonging to this new temperature. This formation

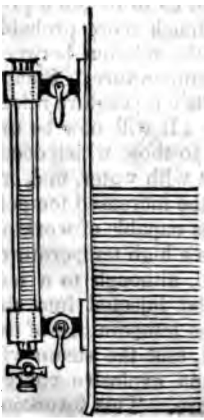
of new vapour within the original space might be so sudden that none of the usual means will suffice to give vent to it, and the boiler must give way.

Such injection of water into a space occupied by intensely heated steam may take place on the opening of the safety-valve, or on letting steam from the boiler into the engine, in order to set it in motion. In either case the water will foam up, mixed with steam, as occurs when a culinary vessel boils over. The injection of water from the feeding apparatus may also produce a similar effect.

67. The height at which water stands in a boiler may be indicated by gauge-cocks, or by a water-gauge.

The gauge-cocks are situated on one of the ends of the boiler. They are usually three in number. The uppermost is situated above the proper level of the water; the second nearly at that level; the third beneath it. When the first is opened, if water issues from it, the boiler is too full; when the third is opened and steam issues, the water stands too low. It is necessary, in observing the indications of these gauge-cocks, to allow time for any water which may have lodged in the stopcocks to be blown out.

Fig. 27.



The water-gauge, represented Fig. 27, is a glass tube, inserted at its ends into two tubes, proceeding, one from the top, the other from the bottom of the boiler. Water will, in consequence, occupy this tube to

the same height at which it stands in the boiler itself.

68. Boilers may be supplied with water, or fed by self-acting apparatus, with great ease when they generate low steam. In this case, no more is necessary than to pass a tube through the upper surface of the boiler, and permit it to descend nearly to the bottom. A column of water will be supported in this by the excess of the tension of the confined steam over that of the atmosphere; and as the water in the boiler is expended, some will enter it from the pipe. If, then, the pipe be kept full, the supply of the boiler will be exactly equal to the quantity evaporated. This pipe may be kept full in either of two ways: 1st, by supplying it with water in such quantities as to cause an overflow; or, 2d, by adapting it to a cistern, with which it communicates by a valve, and causing the valve to open whenever the level of the water in the pipe descends beyond the proper limit. The latter object is effected by a float within the boiler, connected by a lever to a valve in the bottom of the cistern.

An apparatus of this description, as adapted to Watt's boiler, is shown in fig. 25, on p. 68.

In boilers which generate high steam, no other method of feeding has been introduced except the forcing pump. As it is impossible to make this supply exactly the quantity of water which is boiled away, it is made to furnish more than this exact quantity. It can therefore be set in action only at intervals. Self-acting apparatus, to cause the water raised by this pump to enter the boiler or run to waste at pleasure, has been contrived, but has not come into extensive use.

The force-pump is itself moved by the engine, and the feeding apparatus is thus dependant on the mo-

tion of that instrument; while, whether it shall force water into the boiler or not, is wholly at the option of the engineer. A feeding apparatus for high steam boilers, which shall be wholly independent of the motion of the engine and of the attention of the engineer, is therefore still a desideratum.

69. The danger which may arise from the accumulation of steam under ordinary circumstances is pointed out by the steam-gauge. This, in its most usual form, is a bent tube or inverted siphon of iron, adapted to the pipe which conveys steam from the boiler to the engine. The length of each of the branches of this pipe must be equal to the measure in inches of mercury, of the utmost tension of the steam for which the boiler is calculated. The bend of the tube is occupied by mercury, sufficient in quantity to fill either branch. When the steam in the boiler has the tension of a single atmosphere, this mercury will stand at the same level in both branches of the tube. As the tension of the steam increases, the mercury will be forced up the outer and open branch of the tube, and depressed in the other; the difference in the respective levels will be the measure of the tension of the steam. But the depression in one branch is exactly equal to the elevation in the other. It is therefore sufficient to measure the latter, which is done by a rod which floats on the surface of the mercury. This rod is divided into inches, each of which is equivalent to $\frac{1}{15}$th of an atmosphere, or 1 lb.

There are various other forms of steam-gauge, all of which act on the same principle.

70. Any accumulation of steam beyond the prescribed limit of tension, is obviated by the safety-valve.

A safety-valve is a plate of metal ground to the shape of a frustum of a cone; this is fitted to a seat of the same form, adapted to the upper part of the boiler. In order to keep it in its place, under the expansive action of the steam from beneath, it is loaded with a weight. This weight may be either applied directly, or through the intervention of a lever. In the latter case, the pressure on the valve exceeds the weight as much as one arm of the lever is greater than the other.

To this pressure must be added the weight of the valve itself, and the sum, divided by the number of square inches in the surface of the valve, gives the pressure on the valve per inch. Instead of a weight, a spring steelyard is now frequently used to determine the pressure on safety-valves. This is more particularly the case in locomotive engines.

71. The instrument best adapted to indicate when the metal of the boiler or the steam has, from any cause, a temperature higher than is consistent with safety, is the common thermometer.

72. Any risk of the bursting of the boiler from this cause may be obviated by adapting to a seat similar to that of the safety-valve, a plate of the alloy called fusible metal. As the same risk is to be apprehended in the flues, a part of them may be formed of plates of lead.

The objection to these methods is, that, after they have acted, the boiler will be open, and therefore useless. In respect to the valves of fusible metal, this objection is removed by an invention of Professor Bache, of Philadelphia, who encloses the valve of fusible metal in a pipe, which terminates in a safety-valve of the usual form; this valve can be made to close the aperture, as soon as vent has been given to the steam, by the melting of the fusible metal.

73. Self-acting dampers have been constructed to regulate the combustion of the fuel. These are, as yet, only applicable to boilers generating low steam.

74. The communication between the flues and the chimney should also be furnished with a damper within the control of the engineer; the ash-pit of the furnace ought to be provided with doors. By the use of these, the heat may be moderated; and when, from a deficiency of water in the boiler, the metal has become intensely heated, the dampers and ash-pit doors should be closed, and the temperature allowed to subside before any water is injected by the feeding apparatus. However well the safety apparatus of a boiler may have been planned and constructed, much still depends upon the capacity and intelligence of the engineer.

75. Boilers, before they are used, require to be proved. The first proof is performed by forcing water into the boiler by an instrument similar to the hydraulic press. The pressure thus given ought to be four times as great as the elastic force of the steam for which the boiler is intended. The second proof consists in loading the safety-valve with twice the weight it is intended to carry when in use. Steam is then generated, and heat continues to be applied until the safety-valve opens. The latter proof can hardly be considered sufficient for a low-pressure boiler, and would be too severe for one intended for very high steam. It would probably be better to subject boilers to a proof by steam having a constant excess of three or four atmospheres beyond that intended to be employed.

76. Steam is applied as a prime mover in instruments which go under the general name of Steam-*engines*. The properties and mode of action of

these engines may be best illustrated by considering the steps which were successively made in their improvement, until they attained the state in which we now find them. Many ingenious persons were, at different times, engaged in investigating the mechanical properties of steam, with a view of applying it to useful purposes; we shall, however, take notice of none but those who planned engines which were actually employed beneficially.*

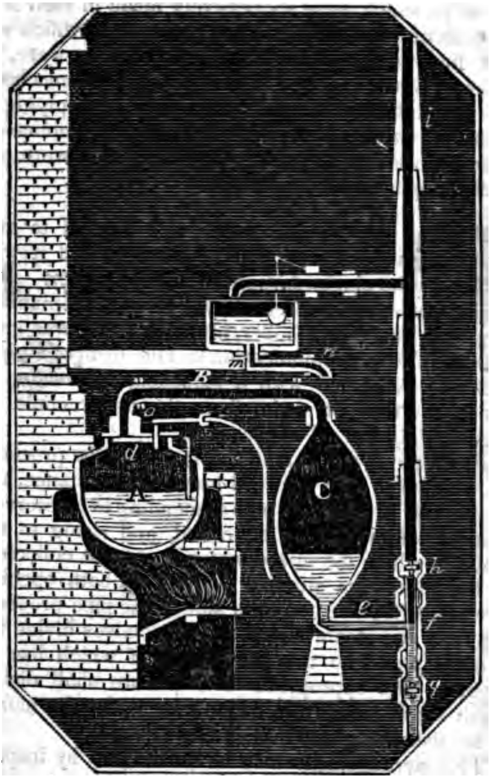
77. The first engine which was applied to any practical purpose was that of Savary, and it was limited to the single purpose of raising water. His engine was composed of an oval vessel, communicating by a tube with a boiler, in which steam was generated. This communication had the form of a pipe, and was furnished with a stopcock, by means of which the flow of steam from the boiler could be regulated, or cut off at pleasure.

From the lower part of the vessel a pipe proceeded, which was bent outward for a short distance, and terminated in a vertical pipe descending to a reservoir whence water was to be raised, and rising to the place in which the raised water was to be collected. In this pipe were situated two valves, both opening upward, and placed on each side of the pipe proceeding from the steam vessel. These valves divide the vertical pipe into two parts, each of which has its separate and appropriate use, and we shall distinguish these parts from each other under the names of the ascending and descending pipes.

This arrangement may be understood by inspection of Fig. 28.

* For a more complete history, see the author's "Treatise on the Steam-engine."

Fig. 28.



A. Boiler.
B. Steam pipe.
C. Steam vessel.
d. Steam valve.
e. Horizontal pipe proceeding from the lower part of the steam vessel.
f g. Descending pipe, having a valve at g.
h i. Ascending pipe, having a valve at h.
m n. Pipe to furnish cold water for condensing the steam, having a stopcock at n.

The manner in which this engine acts is as follows, viz.:

The water in the boiler having been raised to a temperature of 212° or upward, the stopcock on the steam pipe is opened. Steam therefore flows towards the steam vessel, which it finds, in the first instance, full of air. The steam, being lighter than air, tends to occupy the upper part of the steam vessel, and thus displacing the air, causes it to open the valve on the ascending pipe, and to flow out through that channel.

The steam vessel having been thus filled with steam, cold water is permitted to flow over its surface by opening the stopcock *n*. The valve on the steam pipe is closed at the same instant. The steam being thus condensed, a vacuum would be formed in the steam vessel were it not that the air in the ascending pipe makes its way through the valve *g*, and is followed by water, forced upward from the reservoir below by the pressure of the atmosphere.

This first part of the action of Savary's engine resembles that of a common pump, and is limited in practice to a height of about twenty-five feet. When the whole of the steam is condensed, the steam vessel will (except after the first condensation, when the air originally contained in the descending pipe will be present) be filled with water.

The flow of cold water over the surface is now stopped, the stopcock on the steam pipe opened, and the steam again flows from the boiler. The valve on the descending pipe is at once closed, by the weight of the water in the vessel, and the pressure of the steam. If this pressure exceed that of an atmosphere, the valve on the ascending pipe is opened, and the water forced upward through that pipe to a height which will depend on the tension of the steam

generated in the boiler. If that tension amount to two atmospheres, this height will be thirty-four feet, and thirty-four feet more for each additional atmosphere. Savary did not attempt to use steam of greater tension than three atmospheres, and hence the height to which water was raised by the two actions of the steam vessel did not exceed ninety feet.

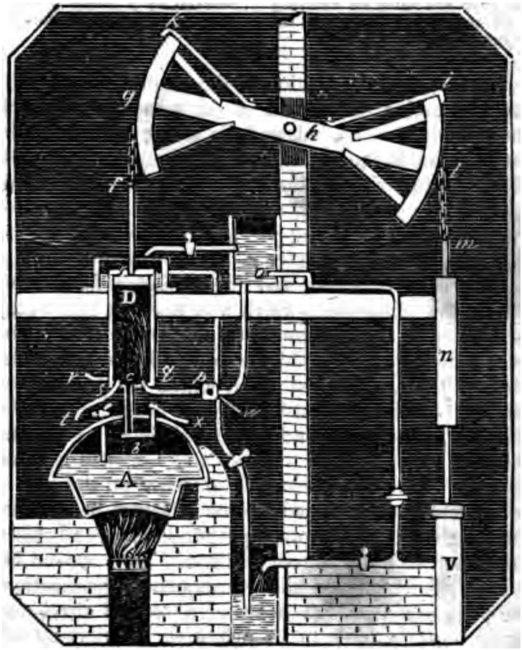
In order to employ the steam which would otherwise have been wasted, or would have accumulated in the boiler to a dangerous degree of tension, a second steam vessel was employed, communicating with the same boiler and the same vertical pipe, and the two vessels were made to act alternately.

78. This engine is liable to all the objections which will be stated as applicable to that which superseded it, as well as to some which are peculiar to itself. The latter are: that it is limited in its action, raising water no more that ninety feet; and that, on account of its employing high steam, it was very unsafe, in consequence of the imperfection, both of materials and workmanship, which existed at the time it was in use.

79. These objections were removed in the engine of Newcomen and Cawley. In this the steam was employed for no other purpose than to form a vacuum by its condensation, and was required to possess no higher tension than a single atmosphere. The actual prime mover was the pressure of the atmosphere, which was employed to raise a weight, and this weight, in its descent, worked a pump. The pump, being of the description called forcing, had no limit of height other than the strength of the materials of which it was composed.

The form of this engine, in its most perfect state, is represented in Fig. 29.

Fig. 29.



A. Boiler.
b. Steam valve.
b c. Steam pipe.
D. Cylinder open at top.
e. Piston fitted airtight to the cylinder.
e f. Piston-rod.
f g. Chain by which the piston-rod is connected to the lever beam.
g h i k l. Lever or working beam, having circular segments at each extremity, in order to adapt its reciprocating circular motion to the rectilineal motion of the piston and pump rods.
l m. Chain by which the pump-rod is attached to the lever beam.
m n. Pump-rod loaded with a weight at *n.*
o p q. Condensing pipe.
p. Condensing valve.

r. Snifting valve.
s t. Pipe and valve for carrying off condensed steam and injected water.
V. Pump.
w x. Hand gear. This was worked by a frame or rack suspended from the working beam.

In the primitve position of the engine, the beam is inclined under the action of the weight with which the pump-rod is loaded, and the piston is in its highest position in the cylinder. The cylinder being full of air, in order to set the engine in action the steam valve *b* is opened, and the steam, passing into the cylinder, rises to the upper part, and expels the air through the snifting valve *r*. The whole of the air having been expelled, and the cylinder filled with steam, the condensing valve *p* is opened, and water is injected. By the stream of cold water thus introduced, the steam is rapidly condensed, and a vacuum formed beneath the piston, on which the pressure of the atmosphere acts with sufficient intensity to force it down to the lower end of the cylinder. The condensing valve is now closed, and the steam valve opened. The equilibrium of pressure on the piston being restored by the admission of steam beneath it, the weight on the pump-rod preponderates, and raises the piston to its primitive position. By a second injection of water and the consequent condensation, the piston is caused to descend a second time, and again brought back to its primitive position by admitting steam beneath it.

The pump therefore is worked by a descending weight; the weight is raised by the pressure of the atmosphere; the steam is applied to restore the equilibrium of pressure for the purpose of allowing the weight to act, and to form a vacuum, in order to render the pressure of the atmosphere efficient.

80. This engine continued to be used for many *years, during* which it was receiving continual im-

provements, the most important of which was a method of opening and shutting the steam and condensing valves by the motion of the engine. It assumed its most perfect form in the hands of Smeaton. At length Watt, being employed to repair a model of the engine of Newcomen and Cawley, was surprised at the great quantity of steam which was used, and the great bulk of water required for condensation. He was thus led to make experiments upon the volume of steam generated by a given volume of water, and the volume of water which the condensed steam was capable of heating to the boiling point. In the course of these experiments he discovered the latent heat of steam, at about the same time in which the general law of latent heat was discovered by Black.

By this discovery the defects of the engine of Newcomen and Cawley became apparent. It was now seen that the interior of the cylinder and the lower side of the piston being cooled down to a temperature of about 100° at each condensation, the steam which first issues from the boiler must part with its latent heat and be converted into water, until the whole is heated up to the temperature of 212°, and thus, until that temperature is reached, the equilibrium on the opposite sides of the piston will not be restored. In this way, five times as much steam is wasted as would be necessary to fill the cylinder, and thus six times as much fuel is used as would suffice to produce the requisite effect, provided the expenditure of latent heat could be prevented.

81. In order to save this latent heat, Watt proposed to use a separate vessel for the condensation of the steam. As this vessel would speedily fill up with the water injected for the purpose of condensation, it became necessary to provide for the removal of that fluid. Two methods presented themselves.

The first consists in placing the condenser at least thirty-four feet above a reservoir of water, with which it communicates by a pipe. As a column of water of greater height than thirty-four feet cannot be supported by the pressure of the atmosphere, the condenser would thus be kept in the state of nearly a perfect vacuum. This method is, however, limited in its application, from the difficulty of finding situations exactly suited to its use. It was therefore rejected. The other method consists in adapting a pump to the condenser, by which all the matter that vessel contains may be drawn out.

As a pump of the usual construction is resisted in its motion by the pressure of the atmosphere upon the whole surface of the piston, a head was adapted to the barrel of the pump, through which the piston-rod was caused to work in an airtight collar. A spout was placed upon the side of the barrel, and furnished with a valve, through which the steam, air, and heated water were discharged.

This pump goes by the name of the air-pump, from the resemblance of its structure to the air-pump of Smeaton.

82. The water discharged by this pump is still warm; it is therefore used for feeding the boiler. For this purpose it is received in a small reservoir, whence it is conveyed by a pump prepared for the purpose to the feeding apparatus of the boiler.

83. The water intended for the condensation o the steam, and injected into the condenser, is fur nished by a third pump. The last two of these ar known respectively by the names of the hot and co water pumps.

84. Finally, Watt proposed to use the steam its *as the prime mover*, in the place of the pressure of t

atmosphere. For this purpose, the piston-rod was made to work through collars, in a cover or head adapted to the cylinder. Steam was conveyed from the boiler to the upper side of the piston, where it acted by its pressure, while that beneath the piston was passing into the condenser. The downward stroke having been completed, the equilibrium of pressure upon the piston was restored by means of a side pipe furnished with a valve. This pipe forms, when the valve is opened, a communication between the upper and lower end of the cylinder, and the weight adapted to the pump-rod will now preponderate and draw the piston up, the steam passing freely, during this upward motion, from the upper to the lower side of the cylinder, through the side pipe.

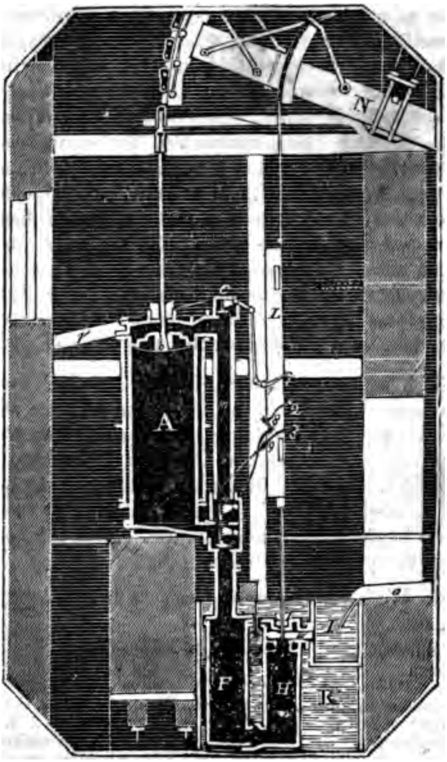
85. The valves, which, in the original form of Newcomen and Cawley's apparatus, had been worked by hand, were, by a subsequent improvement, worked by a frame suspended from the working-beam. Watt retained this method in his single-acting engine, making it work his three valves, instead of the two required in the atmospheric engine. This method was called the plug-frame and hand-gear.

86. Watt's single-acting engine is represented in Fig. 30.

A. Cylinder.
b. Piston.
c. Steam valve.
d. Equilibrium valve.
e. Eduction valve.
F. Condenser.
g. Jet-pipe and injection valve.
N. Working-beam.
o. Cold water pump.
r. Steam pipe.
H. Airpump.
I. Hot water cistern.
K. Cold water cistern.
L. Frame by which the hand-gear or levers 1, 2, 3, of the valves *c d e*, are worked.
m. Side or equilibrium pipe.
u. Foot valve.
w. Delivering door.

87. The single-acting engine produces an alternating motion, and works only during the descent of

Fig. 30.



the piston. It is therefore unfit for almost any purpose except pumping. In order to apply steam to manufacturing purposes, it was necessary,

(1.) That the piston should be forced upward as *well as downward.*

(2.) That the connexion between the piston-rod and the working-beam should be rendered rigid, and, at the same time, allow the rectilineal motion of the first to adapt itself to the circular motion of the other.

(3.) That the reciprocating motion of the lever-beam should be converted into one continuous and circular.

The first of these requisite changes was effected by a second side pipe, by the suppression of the equilibrium valve, and the substitution of two new valves, the one to admit steam to the lower side of the piston, the other to convey steam from its upper side to the condenser.

The second property was obtained by an apparatus called the parallel motion.

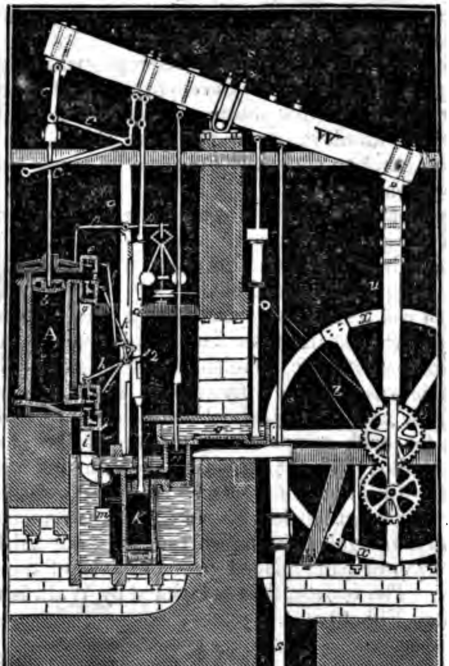
The third, by substituting a rod moving on a pivot for the pump-rod and chain.

This rod had at its opposite end a wheel, the teeth of which caught in another wheel of equal diameter and number of teeth, attached to a fixed axle. Upon this axle was fastened a fly-wheel. By this arrangement, the axle and fly-wheel were caused to revolve twice for each reciprocating motion of the piston. The method had the name of the sun and planet wheel. In order to control the engine when the steam varied in tension, or when the resistance was subject to irregularities, a governor was added, driven by a strap or band placed over the axle of the fly-wheel. The engine, thus completed by Watt, is represented Fig. 31.

A. Cylinder.
b. Piston.
c c c. Parallel motion.
d. Plug frame.
e e. Steam valves.
f f. Hand-gear working steam valves.
g g. Condensing valves.
h h. Hand-gear for condensing valves.
i. Eduction pipe.
K. Airpump.
l. Airpump rod.
m. Condenser.

n. Additional airpump (no longer used).
o. Hot water cistern.
p p. Levers moved by the governor, to act on throttle valve.
q. Governor.
r. Hot water pump.
s. Cold water pump.
t t. Sun and planet wheel.
u. Connecting rod.
W W. Lever beam.
x x. Fly-wheel.
Z. Band which drives the governor.

Fig. 31.



Instead of the sun and planet wheel, a crank is

now universally used. The fly-wheel not only serves to regulate the motion, but also to cause the crank to pass through both semicircles. Were there no fly-wheel, it might merely oscillate in the same semicircle.

In going thus from one semicircle to another, the crank is said to pass the centre.

88. The importance of the double-acting engine of Watt requires that we should describe it more in detail, and in reference to the improved form which has since been given it.

The steam is conveyed to the engine through a pipe, in which is situated a valve known by the name of the throttle valve. This has the figure of a circular plate, and is suspended on an axle passing through its horizontal diameter. It may therefore lie in the direction of the pipe, when it will oppose but little resistance to the passage of the steam, or, by moving through a quadrant, may close the pipe altogether.

89. The steam passes through the steam pipe to one of the side pipes, and thence alternately to chambers situated at the two ends of the cylinder, known by the name of steam chests.

Each steam chest is divided into three parts by means of two partitions. The middle part of each steam chest communicates with the cylinder, the upper part with the side pipe just spoken of, the lower part with the other side pipe, which is prolonged until it enters the condenser. The latter is called the eduction pipe.

90. Each partition has a circular opening, ground into a conical form, to which a conical valve is fitted. When the upper valve of either chest is opened, steam flows through it into the cylinder; and

when the lower valve is opened, steam flows through it from the cylinder into the condenser. The four valves are therefore united in pairs, so that a steam and a condensing valve of two separate steam chests shall be opened and shut together.

91. The valves were formerly moved by adapting a rack to each; this rack was caught by the teeth of a segment, which was moved by a lever passing airtight through the sides of the steam chest. They are now usually moved by vertical rods. In the top of each steam chest a hole is left, through which the rod of the upper valve passes, and the joint is secured by a stuffing-box or collar containing hemp and tallow. The rod of the upper valve is bored and ground, the rod of the lower valve is solid, and passes through the cavity bored in the rod of the upper valve.

In a more recent form, planned by Mr. Hall, of New-York, the valves do not lie vertically beneath each other, and each valve has a separate collar for the passage of its rod.

92. Instead of four conical valves placed in two steam chests, and two side pipes, an arrangement which goes by the name of the slide or D valve is often used. To construct this, a pipe having the figure of half a cylinder is adjusted to the side of the cylinder, having its flat surface in contact with the latter. The steam passages enter into this pipe. Within this another pipe is placed of less length, which closely fills, and is ground to fit the outer pipe at its two ends, and these parts are at such distances that when the one covers the steam passage nearest to it, the other shall leave its corresponding steam passage open. The intervening part of the inner pipe does not fill the outer pipe. The steam is ad-

mitted into the middle of the outer pipe, and fills the space between the two. The inner pipe being moveable by the action of the engine, the steam will, as this pipe ascends and descends, pass alternately into the steam passages. Openings are cut in the flat face of the inner pipe of the same size as the steam passages, and at such distances that, when the one corresponds with its adjacent passage, the other shall not. Through these openings the steam passes alternately to the inner pipe, and then to the lower part of the outer pipe which is in communication with the condenser.

93. The cylinder is usually made in three pieces: namely, a hollow metallic vessel, having the figure imported by its name, a lid or cover, and a bottom or bed-plate. These three parts are turned to fit each other, and firmly fastened by screw-bolts and nuts. The joints are rendered tight by hemp coated with white lead and oil. In the middle of the cover is an opening for the passage of the piston rod, and to this is adapted a stuffing-box filled with hemp and tallow.

The passage for steam to and from the upper side of the piston is cast upon the hollow cylinder; the lower passage is cast in the bed-plate.

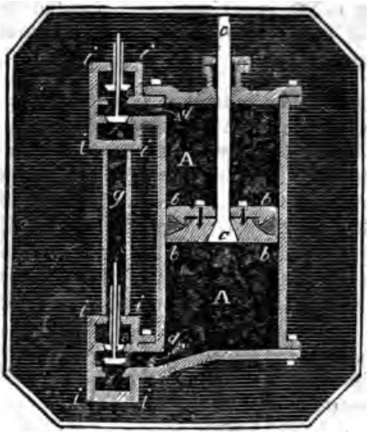
94. The piston is formed of two pieces, united by screw-bolts and nuts. Between these pieces is interposed a packing of hemp coated with tallow. As the packing wears, it may be tightened from time to time by the nuts.

The lower end of the piston-rod is enlarged into the figure of a truncated cone. This fills a similar cavity in the piston, and the two are fastened by drawing a key through an eye in the piston-rod immediately above the upper plate of the piston.

The space through which the piston moves, called its stroke, is usually one half more than its own diameter. The cylinder must be as much longer as will leave room for the piston, and prevent it from striking at either end of its stroke.

This arrangement of steam pipe, steam chests, valves, cylinder, piston, and piston-rod, will be understood by inspection of Fig. 32.

Fig. 32.



A A. Cavity of cylinder.
b b b b. Piston.
c c. Piston-rod.
d d. Steam passages.
e e. Steam valves.
f f. Condensing valves.
g. Side pipe; the other is supposed to be removed, in order to exhibit the steam chests and valves.
h. Stuffing-box.
i i i. Steam chests.

Metallic packing is now used, in preference to hemp and tallow, for rendering the piston tight. In the best form of metallic packing, the steam which moves the piston acts as a spring in order to keep the packing tight.

95. The condenser is also a cylindric vessel, formed of three pieces, the lower of which is prolonged, and serves as the basis of the airpump. One of the side pipes terminates in the condenser, which thus receives steam alternately from the opposite sides of the piston. The condensation is performed partly by keeping the surface of the condenser cool, by immersion in a cistern of cold water, and partly by the injection of water. The injection is effected by a pipe passing from this cistern into the condenser. The quantity of water injected is regulated by a cock called the injection valve. The pipe often terminates towards the condenser in a nozzle, pierced with holes like the rose of a watering-pot.

Another form of condenser is now coming into use, the invention of Hall. This is composed of a series of pipes, immersed in a cistern through which a current of cold water continually flows. The water condensed in these pipes is pumped back into the boiler. The waste caused by the generation of steam is therefore identically replaced, and the boiler, being wholly fed with distilled water, is not liable to the deposite of sediment, or of the saline matters which are finally crystallized, whenever water containing them is employed.

96. The communication between the condenser and airpump is by a horizontal rectangular passage. In this is situated the lower valve of the airpump, called the foot valve; it has the form of a door suspended on hinges from its upper side.

97. The airpump is closed at top, and its piston-rod works through a stuffing-box. Its piston is called the bucket, and has a valve. This is usually of the figure called a butterfly valve, being composed of two leaves attached by hinges to a diameter of the piston.

The water, air, &c., are discharged from the air-pump by a rectangular spout, on which is situated a valve similar in form to the foot valve, and which is called the delivering door. The water discharged by this is received in a small cistern called the hot water cistern, in order that it may be used while warm to feed the boiler. Where Hall's condenser is used, the airpump forces the condensed water immediately into the boiler.

98. In the cold water cistern is immersed not only the condenser, but the airpump also.

99. The cold water cistern is supplied to overflowing by the constant action of the cold water pump.

100. The hot water pump conveys the warm water to the feeding apparatus of the boiler.

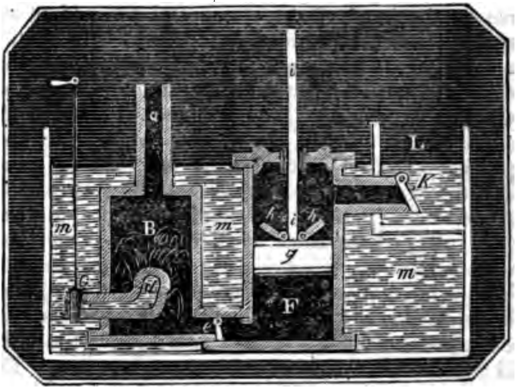
101. The capacity of the condenser in engines used for manufacturing purposes has most frequently been made one eighth of that of the cylinder; its usual dimensions being each one half of those of the latter. In boat engines this capacity is increased one half, and the cold water cistern is dispensed with. The airpump has the same capacity as the condenser.

The arrangement of condenser, airpump and its valves, cold and hot water cisterns, may be understood by inspection of Fig. 33.

102. The state of the vacuum in the condenser is ascertained by means of the vacuum gauge. This is similar in principle and construction to the barometer gauge of an airpump. An indicator has been used for the same purpose. This is a piston supported in a tube by a spring, which is forced down by the pressure of the atmosphere. The value of this spring is ascertained by experiment.

103. In adapting the condensing engine to steam-

Fig. 33.



a. Eduction pipe.
B. Condenser.
c. Injection valve.
d. Injection pipe and nozzle.
e. Foot valve.
F. Airpump.
g. Bucket.
h h. Butterfly valve.
i i. Airpump rod.
K. Delivering door.
L. Hot water cistern.
m m m. Cold water cistern.

boats, the weight of the water contained in the cold water cistern, or the diminution of buoyancy in case of its being in free communication with the water in which the vessel floats, would be a disadvantage. In order to suppress this cistern, without diminution of the power of condensation, the capacity of the condenser is increased to half that of the cylinder. The hot water cistern also, instead of being placed on one side of the airpump, is set upon it, and the delivering door takes the form of valves in the lid of the airpump.

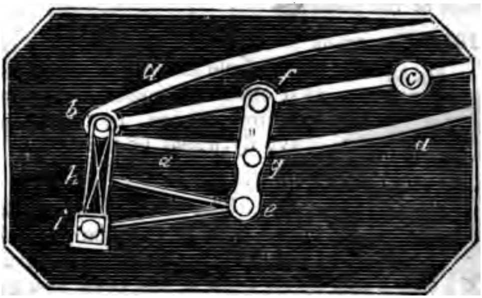
104. The working-beam has usually three times the length of the stroke of the piston. The piston-rod is joined to it by a pair of thin bars called straps;

these terminate in collars, adjusted to pivots or centres on the head of the piston and the end of the working-beam. From a point half way between that to which these straps are attached and the centre on which the working-beam oscillates, another pair of straps is suspended. The two pairs of straps are united by a rod called the parallel bar, from its having that position in respect to the working-beam. Half the arm of the working-beam, the two pairs of straps, and the parallel bar, have the figure of a parallelogram, whose sides are constant in length, but whose angles may change their dimension. In order to guide the motion of its angular points, the angle of the parallelogram formed by the parallel bar and the second pair of straps is connected by a rod to a fixed point. This rod is called the radius bar. The angle with which it is connected is therefore caused to describe an arc of a circle, of the same number of degrees with that described by the end of the working-beam, but having its convexity turned in an opposite direction. Three angles of the parallelogram, therefore, describe circular arcs, and the fourth is thus caused to describe a path which does not sensibly differ from a straight line. This fourth point is that where the piston-rod is attached to the straps. The whole apparatus goes by the name of the parallel motion. There is another point in this system of bars and straps which also describes a straight line. This point is situated in the second pair of straps, where a line drawn from the centre of motion of the working-beam to the point where the first pair of straps is attached to the piston rod, cuts the second pair of straps. To this point the rod of the airpump is attached. The rods of the cold and hot water pumps do not require a parallel motion; they are attached by collars to gudgeons in the

working-beam, at distances of one third and one half of its length from its centre.

The parallel motion is exhibited in Fig. 34.

Fig. 34.



a a a. Represents half the working-beam.
b i. Straps which connect the working-beam to the piston-rod.
i e. Parallel bar.
e f. Second pair of straps.
e h. Radius bar.
g. Centre to which the air-pump rod is applied.

For the parallel motion, a cross-head upon the piston-rod, working in two vertical guides, is now often substituted. This method is the only one now used in this country, and is, for many reasons, superior to the parallel motion.

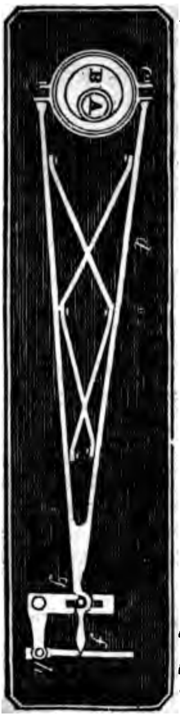
105. The working-beam was at first of wood, but is now usually made of cast iron. The centre of its own motion, with those of the parallel motion and pump-rods, are solid cylinders of wrought iron, or steel, carefully turned, and passed through the working-beam.

106. In many American engines the working-beam is a frame of cast iron, surrounded by a strap of wrought iron, of the figure of a lozenge. In this construction, a greater degree of strength is obtained

with less weight of material. The connecting rod of English engines has a length equal to twice, and in American engines three times the stroke of the piston. The effective length of the crank is half the stroke of the piston.

107. The crank is compelled to describe a complete circle instead of oscillating, as it otherwise might, in the same semicircular arc, by adapting a heavy fly-wheel to the axle of the crank.

Fig. 35.



108. The method of working valves by a plug-frame suspended from the lever beam, or by motions taken from it, has been in a great degree superseded. The plan most frequently adopted at present is composed of the eccentric and the tumbling shaft. The tumbling shaft has the shape of a crank and its axle; cams are formed upon the latter, which, by means of rods, serve to open valves when of a conical figure. These valves shut by their own weight when the action of the cam ceases.

The construction of the eccentric

A. Eccentric opening, through which the axle of the fly-wheel passes.
B. Iron plate of a circular shape.
c. Iron ring embracing the eccentric plate.
d. Triangular frame.
g. Notch falling upon a part of the tumbling shaft.
g h Crank of the tumbling shaft.
f. Connecting rod by which a slide valve may be worked.

is as follows :- a circular plate is pierced by a circular hole, whose centre is not the same as that of the plate itself. This plate is wedged to the axle of the crank, and revolves with it. The plate is surrounded by a circular ring, which does not revolve with it. To this ring two bars are attached, forming two sides of an isosceles triangle, and the frame thus formed is strengthened by braces. During the revolution of the plate with the axle of the crank, the end of this triangular frame has a reciprocating motion. This motion is communicated to the tumbling shaft by forming a notch near the end of the eccentric; this notch drops on the crank of the tumbling shaft.

An eccentric is figured on the opposite page.

109. Watt was in the habit of using steam having a tension about one sixth greater than an atmosphere, say, capable of exerting a pressure of 17½ lbs. per square inch. At this tension he found that the efficient pressure on the piston was no more than 10 lbs. His rule for estimating the power of a double-acting condensing steam-engine is therefore as follows: Multiply together the area of the piston, the length of stroke, the number of strokes per minute, and the constant number 10; divide the product by 33,000. The quotient is the horse-power.

For each horse-power the evaporation of a cubic foot of water per hour will suffice, and the consumption of bituminous coal will be 10 lbs. per hour to each horse-power of the engine.

This rule was founded on the belief that there was a loss of power equivalent to 7½ lbs. per square inch, in consequence of the imperfection of the vacuum in the condenser, the friction, and the obliquity of action in the crank. Now, the tension of vapour corresponding to the usual temperature of condensation is never more than 2 lbs. per inch: the crank, from

the fact that its most favourable positions correspond with the maximum action of the steam, and its least favourable positions with an absolute cessation in the flow of the vapour, causes but a small loss by obliquity; and the friction is far from being sufficient to make up the difference. The rule of Watt is, notwithstanding, correct for the cases to which his observation was limited, namely, of a piston moving with a velocity of from 200 to 250 feet per minute. At other velocities the rule would be untrue. The actual cause of the difference between the efficient pressure on the piston, and the tension of the vapour on the boiler after the friction has been allowed for, is the fact which has been referred to in the introduction, that all forces, except such as are constant, exert less power upon a body in motion than they do upon a body at rest; and in the case under consideration, if we were to suppose the piston to be moving with the same velocity as the steam was capable of following it, no pressure whatever would be exerted. This simple and obvious fact has hitherto escaped the notice of all writers on the steam-engine. The mathematical investigation of the pressure upon the piston due to a given tension of steam in the boiler and a given velocity of the piston, would be attended with considerable difficulty. The Ch. de Pambour, by considering the question in another point of view, has been led to formulæ which are capable of expressing the relation between the tension of steam in the boiler, the state of the vacuum in the condenser, the velocity of the piston, and measure of the work which may be performed.*

* The foundation of Pambour's new theory of the steam-engine rests upon the following equation: in which S is the quantity of water evaporated per minute; m the ratio of the volume of steam generated under the given pressure P in the boiler, to that *of the water.* $m\ S$ is therefore the volume of steam formed per

The rule of Watt, however, has been so long in use that it will probably be retained, not as a mode of measuring the duty of a steam-engine, but as one by which an engine may be described in contracts between the purchaser and the maker. The denomination in horse-power has therefore not been changed, although, by an improvement in the mode of using steam, the duty has been increased in some cases more than fourfold.

The duty of an engine is estimated in the weight which can be lifted one foot by the combustion of a bushel of coals. In Watt's first engines the duty was 20 millions of lbs. By the introduction of the expansive action of steam, the duty has been raised, in some instances, to more than 90 millions.

110. Steam of greater tension may be used in the same manner as low steam in the condensing engine. To do this in a given engine would require an increase in the fire surface of the boiler, and, as the density increases with the tension, though in a less ratio, the advantage gained would not be equivalent to the additional expenditure of fuel. A given engine might thus be made to do more work, but the extra work would cost more than if performed with an engine of increased size. There would also be a

minute in the boiler; a is the area of the piston, v its velocity, and R the resistance of the load. Then,

$$v=\frac{m\,S}{a}\cdot\frac{P}{R};$$

whence we obtain for the resistance which may be overcome,

$$R=\frac{m\,S\,P}{a\,v};$$

and for the quantity of water to be evaporated,

$$S=\frac{a\,v\,R}{m\,P}.$$

difficulty in keeping up a vacuum, unless the size of the condenser and the power of the airpump were increased.

111. If, however, the communication between the boiler and engine be made intermitting, and the steam flow only during a part of each stroke, the tension of the steam generated in the boiler will be necessarily increased, even in higher proportion than the diminution in the time of its flow. Thus, if the steam be cut off at half stroke, its tension will be more than doubled. When admitted of such increased tension into the cylinder, and cut off after the cylinder is partly filled, the steam will expand and continue to act by its elastic force; and if its final expansion do not reduce its tension below the measure of resistances, the stroke will be completed. In this way, by cutting off the steam early in the stroke, vast advantages have been gained, and, in some instances, the effect of a given engine and boiler has been more than quadrupled, without any additional expenditure of fuel.

112. In order to fit an engine for acting expansively, the boiler must be made of such form and material as will enable it safely to bear the increased tension of the steam; a valve, to cut off the steam at the required part of the stroke, must be placed in the steam pipe, and apparatus for working it provided; instead of a common pump, the hot water pump must be capable of forcing the supply into the boiler, and the feeding apparatus appropriate to a low pressure boiler removed.* Of all modes in which steam has yet been applied, this is found to be most advantageous.

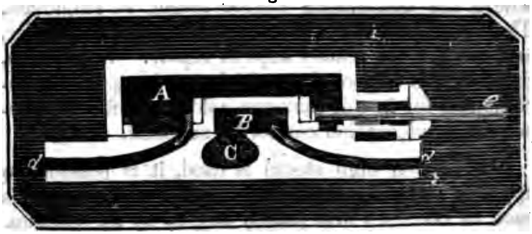
* For a full exposition of the advantages of a condensing engine acting expansively, see the author's "Treatise on the Steam-*engine.*"

113. High steam may be also used without being condensed. The engine is, in this case, said to be "high pressure." This method was originally proposed as early as the time of Watt's improvement, by Oliver Evans, an American engineer. It was carried into effect by him and by Trevithick in England at the same time, in 1801.

114. A high pressure engine may have the same general form as a condensing one, being composed of a cylinder, parallel motion, working-beam, connecting-rod, crank, and fly-wheel. The cold water cistern, condenser, and airpump are unnecessary, and are therefore suppressed. For the hot water cistern is substituted a reservoir, in which water may be heated by the waste steam from the cylinder; this is supplied by a common pump, and the water is forced from it into the boiler by a forcing pump, both worked by the engine.

115. Instead of the conical valves which have been described, or the long slide valve, a short slide valve is usually substituted. The structure and use of this may be understood from Fig. 36.

Fig. 36.



A. Steam chest.
B. Moveable septum, which alternately covers the entrances of the side pipes.
c c. Rod connected with the tumbling shaft.
d d. Side pipes.

116. The cylinders of high pressure engines are frequently placed horizontally. In this form of engine the parallel motion and working-beam are suppressed, and the connecting-rod makes a communication directly between the head of the piston-rod and the crank.

117. The high pressure engine derives its value in practice from the fact that the tension of steam increases in a higher ratio than its density, when its temperature is elevated: and thus, although it is always resisted by the pressure of the atmosphere, a point will be reached at which its duty will be exactly equal to that of a condensing engine working with low steam not cut off. This equality is attained when the tension of the steam employed is equal to three atmospheres. A farther increase of tension will increase the duty of the engine, but in a far less ratio than in the expansive action of the condensing engine.

118. High pressure engines are therefore inferior to the condensing engine acting expansively in the economy of the power. They have, however, certain merits, which cause them to be used in many cases where the condensing engine might be employed. Their first cost is much less; they are much simpler, and much more readily kept in repair. In addition, they are the only engines which can be applied to locomotion, for in this instance cold water for the purpose of condensation cannot be supplied.

119. When high steam is used, it is possible to apply it upon the same principle on which water is used in Barker's Mill (see § 45), or by its reaction. A very ingenious and efficient engine of this description has been constructed in the United States by Avery. Its duty has been found, by actual experi-

ment, to be superior to that of the high pressure engine and the condensing engine acting with low steam, but inferior to the latter acting expansively.*

120. From a mistaken notion of a loss of power attending the action of a crank, rotary engines, or those in which a continuous circular motion is produced directly by the steam, have been much sought for. This notion is not correct; and even if a successful rotary engine should be constructed, no important advantage would be derived from this cause. There would, however, be a greater degree of simplicity in the gearing of such an engine, which might be of use independently of any other reason. While, therefore, the advantages which projectors have anticipated from rotary engines are not real, there may still be a sufficient gain to warrant an attempt at constructing them.

* For a more full account of the Steam-engine in its most improved forms, see the author's "Treatise on the Steam-engine."

III.

MACHINES MOVED BY DESCENDING WEIGHTS.

121. A WEIGHT tends to descend with a velocity uniformly accelerated. This acceleration may be done away, and the motion rendered uniform after a time, by applying a resistance which increases in a higher ratio than the velocity.

The air furnishes a resistance of this sort, and hence it has been attempted to regulate machines set in motion by a descending weight, by placing leaves or thin plates of metal at right angles to the surface of a horizontal fly-wheel. Were the density of the air constant, this mode of regulation would be perfect; but, in consequence of the continual variations in temperature and pressure, it ceases to be efficient in those cases where accuracy is required.

This is more particularly the case in the clock, where regularity of motion is the only desired object.

122. Failing in the application of the fly with leaves to regulate instruments intended for the measure of time, the pendulum* is now universally applied to the purpose.

A pendulum itself, from its near approach to isochronism, would be a good measure of equal portions of time, were it not that it loses a portion of its motion at each oscillation, in consequence of friction upon its axis of suspension, and the resistance of the

* *For the theory* of the pendulum, see the author's treatise on *Mechanics. See also* Mosely's Illustrations.

air. Its oscillations, in consequence, are not absolutely equal in time, and it finally ceases to oscillate. The force of a descending weight may be applied for the purpose of restoring to the pendulum at each oscillation the motion it has lost, by means of a train of wheels and pinions. As this loss is extremely small, the intensity of the action of the weight is lessened by causing wheels to drive pinions. In this way, too, as the descent of the weight will be checked by the pendulum, reacting through pinions driving wheels, this descent will be slow, and the weight will take a considerable time to pass through a small space. The apparatus, therefore, may continue in motion for several days without occupying much room. The train of wheels and pinions may be made to subserve another purpose, for those which have the slowest motion are capable of registering upon a divided circle the revolutions of those which move faster than themselves, and of subdividing each of their own revolutions.

123. A clock, then, is an instrument intended for the measure of time, and is composed of a pendulum, adapted as a regulator to a machine usually moved by a weight, which machine counts and records the number of the pendulum's oscillations.

124. It is difficult to estimate exactly the quantity of motion lost by a pendulum at each oscillation; it therefore becomes necessary, in order to prevent the clock from stopping, to give it motion by a weight of more intensity than would be barely sufficient. Under the action of such a weight, a tendency to acceleration will ensue, but this will be counteracted by the increased arc in which the excess of force would tend to make the pendulum swing, and an increase in the arc will require a longer time for its descrip-

tion. Thus, after a time, the arc will become constant, and the oscillations equal. A clock is now said to take up its rate, and it will do this the sooner, as the excess of the action of the weight is less. From this it follows that a clock ought not to be allowed to run down, and should be so constructed that the motion may be kept up while the weight is in the act of being lifted back to its primitive position.

It will appear, from what has been stated, that the less the weight that will ensure the clock to go, the better. The weight is therefore never sufficient to cause the pendulum to begin to move, but the latter must be raised through half its arc of oscillation by hand, and then left to itself. The oscillation thus commenced by the falling of the pendulum from the position to which it has been raised, is afterward kept up by the action of the weight.

125. We have supposed the pendulum to be of constant length; but this cannot be the case when the pendulum is composed of a simple metallic rod bearing a bulb, for both are subject to expansion and contraction by alternations of heat and cold. This defect has been obviated by various modifications of the pendulum, by which it is said to be compensated, or caused to remain of nearly invariable length during all the changes of temperature which can occur by exposure to the climate.

Two different principles have governed the construction of compensation pendulums:

(1.) To make the bulb and the rod of such materials, that the expansion of the former upward shall exactly equal the expansion of the latter downward.

(2.) To make the rod of several pieces, acting in opposition to each other, in such manner that the joint expansions of a part of them downward shall be counteracted by the joint expansions of another part *and of the bulb* upward.

The pendulum most in use, which depends for its structure on the first principle, is the mercurial pendulum of Graham. The most familiar pendulum, founded on the second principle, is the gridiron pendulum of Harrison.*

A wooden rod thoroughly seasoned, and protected by varnish from the moisture of the atmosphere, answers as a measure of equal time nearly as well as the best compensation pendulum.

126. The weight which moves a clock is attached to a cord. This cord is wound around a barrel, or is stretched by a counterpoise over a pulley. When the weight is left free, it, in descending, turns the barrel around and uncoils the cord. It is necessary, in order that the weight may be wound up after it has finished its descent, without turning the wheels back again through the whole of their respective revolutions, that this barrel should be attached to the first wheel of the train by some method, which, while it conveys the whole impulse of the weight in one direction, shall permit free motion in the other. This is effected by means of the ratchet and ratchet-wheel; the former of which is attached to the first wheel of the train, the latter firmly fixed to the barrel. The ratchet and ratchet-wheel are represented Fig. 37.

127. In the common eight-day clock there are four wheels, which are enclosed between two plates, in which their axles rest. The first or great wheel has the same axis with the barrel, and is attached to it by means of the ratchet-wheel. The great wheel revolves in twelve hours, and might therefore carry

* For the theory of these pendulums, see the author's "Treatise on Mechanics." For a full account of various compensation pendulums, see Kater, in Lardner's Cyclopædia, article "Mechanics." See also Mosely's Illustrations.

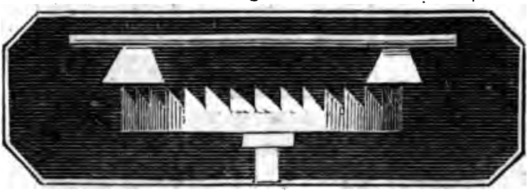
Fig. 37.

the hour-hand, which performs a circuit of the dial plate in that space of time; it has 96 teeth, and turns a pinion of 8 teeth. This pinion is fixed to the same axle with a wheel, which revolves with it in an hour, and is hence called the hour-wheel, or, from its position opposite to the middle of the dial, the centre wheel. The hour-wheel has 64 teeth, and turns a pinion of 8 teeth. This pinion, in the original form of clocks, carries upon its axle a wheel whose teeth are at right angles to the plane in which it revolves, and which is hence called the contrate wheel. The contrate wheel has 60 teeth, and turns a pinion of 8 teeth. The axis of this pinion is vertical, the contrate wheel having the property of communicating a motion at right angles to that in which itself revolves. On the vertical axle of this pinion is situated a wheel, called the swing or crown-wheel, which, of course, revolves in a horizontal plane. This has 30 vertical teeth, unequally inclined at their two faces like the teeth of a saw. Over the crown-wheel lies a rod called the verge, from

which project downward two leaves or pallets that are not in the same plane. These lie over points of the circumference of the wheel nearly opposite to each other, and, as the number of teeth in the crown-wheel is even, they will alternately receive impulses from it, and these impulses are in opposite directions. An oscillating motion is thus given to the verge, at the rate of two vibrations for each tooth of the crown-wheel. The verge is bent downward behind the plate of the clock, and is again bent horizontally outward; the last part is forked, and the pendulum being dropped between the branches, receives from them the motion communicated to the verge. The forked part is called the crutch.

The arrangement of crown-wheel, pallets, and verge is represented in Fig. 38.

Fig. 38.

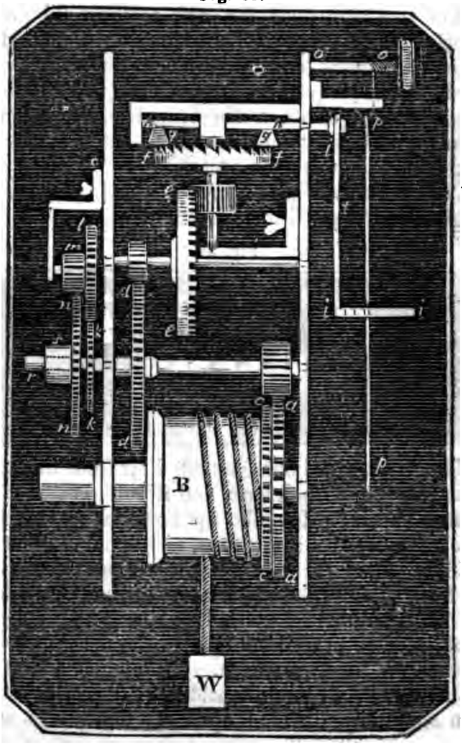


The great wheel being situated far from the centre of the works of the clock, and it being usually considered expedient to make the hour and minute hand revolve upon the same axis, additional wheels and pinions, called the dial-work, are inserted between the front plate of the clock and the dial. Besides, if the hour-hand were carried by the great wheel, it would revolve in a direction opposite to that in which the minute-hand revolves. In clocks where the symmetry of position is considered of less importance than simplicity, a wheel upon the same axis as the

great wheel is made to turn another wheel of the same number of teeth with itself, and which will revolve at the same rate, but in a contrary direction, and the dial-work is omitted.

A side view of the common clock is exhibited in Fig. 39

Fig. 39.



W. Weight.
B. Barrel.
c c. Ratchet Wheel.
a a. Great Wheel.
d d. Centre Wheel.
e e. Contrate Wheel.
f f. Swing, or Balance Wheel.
g g. Pallets.
h h. Verge.
i i i. Crutch.
p p. Pendulum, represented as suspended by a thread from the rod *o o.*

The wheels *k k*, *l k*, and *n n*, with the pinion *m n*, are placed between the front plate and the dial, for the purpose of reducing the motion of the wheel *d d*, which revolves in an hour and carries the minute-hand, to one of a twelfth part of the speed, by which the hour-hand may be carried. The barrel *s*, and the axle of the wheel *k k*, are hollow, in order that the axle of the wheel *d d* may pass through them.

128. The method of converting the continuous motion of the wheels into the reciprocating motion of the pendulum, by a crown-wheel and pallets, has the advantage of great simplicity and cheapness. It is not, however, favourable to accuracy in the division of time.

129. A very simple clock was proposed and constructed by Franklin. This has only three wheels. The first of these revolves in four hours, and has 160 teeth. The pinion of the second wheel has 10 teeth, and the wheel itself 120 teeth. The third or balance-wheel has 30 teeth, and its pinion 8. The dial-plate is divided into four quadrants, each of which is divided in 60 parts, and the hours are numbered from 1 to 12, upon a spiral within the graduated circle; the spiral makes three revolutions between the centre and the circumference. One hand, therefore, serves to point out both the hours and the minutes.

A clock of the same number of wheels, whose great wheel revolves in 12 hours, was planned by Ferguson; but, in order to remove some objections urged

against that of Franklin, he loaded it with parts which are liable to greater ones.

A more beautiful and ingenious modification of the clock of Franklin has been constructed by Breguet, and is represented in Fig. 40. The great wheel of this has 288 teeth, the pinion it drives 6 teeth; the latter is upon the axle of the balance-wheel, which has 30 teeth.

Fig. 40.

This clock, like many other French timekeepers, has an arrangement called the equation, by which the mean time it marks is converted into apparent time. This is rendered expedient by the practice of France, where the apparent time is that by which the concerns of life are regulated, but would be of no value in this country, where we employ mean time. This equation apparatus is of much ingenuity, but is not of sufficient importance to us to need description.

Clocks, except when intended for astronomic purposes, have often an additional set of works for the purpose of striking the hours, and occasionally the half hours, or even quarters. This is moved by a weight, but is locked except just at the time it is to strike, when the other set of works removes the detent. The regulator of the motion is a small fly with leaves.

130. Any mode by which the continuous revolution of a timekeeper can be converted into a reciprocating motion, is called a scapement. The crown-wheel and pallets do not furnish a good scapement, for several reasons. 1. The pendulum swings in too large an arc, and is hence more subject to variation than were the arc smaller. 2. The pendulum and weight are never wholly free from each other, and the former is, therefore, continually subject to the accelerating influence of the latter. 3. A recoil or reversed motion ensues from the mutual action of the weight and pendulum.

These objections have been obviated by various other scapements, by which the arc has been much diminished, the pendulum left free during its entire oscillation, and the descent of the weight completely checked, but without recoil, at the end of each oscillation of the pendulum. When scapements have the second of these properties, they are said to be

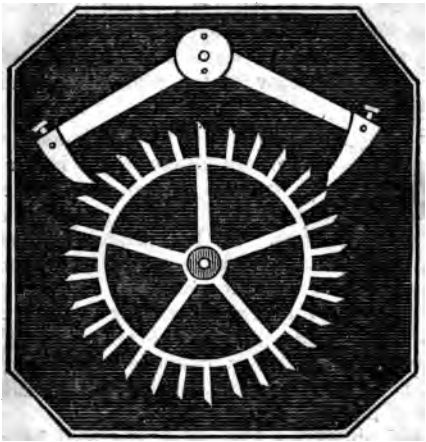
free or detached; when they produce the last effect, the clock is said to make a dead beat. Of these scapements the most interesting are as follows, viz.:

(1.) The anchor scapement, as represented in Fig. 7, page 21.

This is still liable to recoil.

(2.) The improved anchor scapement, by which recoil is obviated. This improvement was the invention of Graham, and a form of it, applied by Reid to a clock in the collection of Columbia College, is represented Fig. 41.

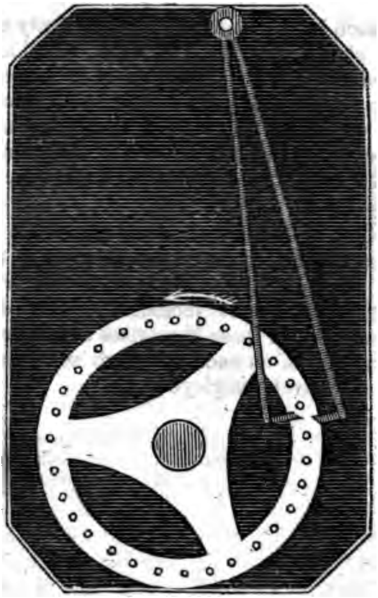
Fig. 41.



(3.) The scapement of Amant or *à chevilles*, represented Fig. 42.

There are various other scapements, of greater complexity, which are applicable to clocks; those which have been described are, however, the most interesting, and sufficient for most practical purposes.

Fig. 42.



131. The best clocks, therefore, in conformity with what has been stated, have one or other of the improved scapements which have been described, a compensation pendulum, and an apparatus for continuing the motion of the great wheel while the weight is in the act of being wound up. In order to prevent wear and lessen the friction, the pallets are often constructed of corundum or other hard stone. In astronomic clocks, which are intended to mark sidereal time, the motion of the hour-hand is taken off from the great wheel in such manner as

to cause it to revolve in twenty-four hours instead of twelve.

With such improvements and great nicety of workmanship, clocks have been constructed which have not varied more than a fraction of a second from their rate for a whole year. The most remarkable instance of this sort, is a clock made by Cumming, the property of Captain Brown, of London, which was used by Kater and Sabine in their experiments on the pendulum.

132. Much of the perfection and cheapness of modern clocks depends upon the application of the mechanical principle of the division of labour. The manufacture of clocks includes sixteen different trades, and each of these comprises several subordinate departments, on each of which separate workmen are exclusively employed.

IV.

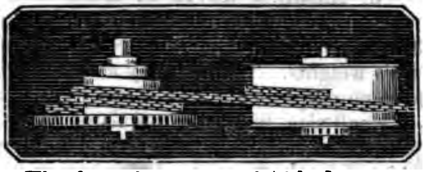
OF MACHINES MOVED BY SPRINGS.

133. It has been stated that clocks are usually moved by weights. Springs may also be employed for the same purpose, and this is usually the case in those of small size, which are regulated by half-second pendulums. Springs, however, are more frequently used in the species of timekeeper called a watch. As these are intended to be portable, they can neither be impelled by a descending weight, nor regulated by a pendulum, for the motion of either of these is interrupted by any disturbance.

134. The spring which acts as the prime mover in a watch, and is called the mainspring, is, as has been stated in § 17, of the figure of a spiral, and is coiled in a barrel, to which it gives motion. This barrel, in moving under the elastic force of the spring, coils a chain around it, drawing this chain from another barrel called the fusee. As the spring acts with a varying intensity, this barrel is made conoidal, and in withdrawing the chain from it, the spring begins to act upon its smallest diameter; but, as the chain is withdrawn, the diameter on which it acts increases. This is effected by cutting a spiral groove around the fusee. The figure which would meet the law of the spring's elasticity, is one formed by the revolution of a hyperbola around its assymtote. As the spring cannot be absolutely homogeneous or uniform in structure, this figure is only an approach to the truth. A figure which will compensate the varying action of

any given spring, is produced by causing the spring itself to act as the moving power in an engine, by which the spiral groove is cut. The barrel which contains the mainspring, the fusee, and chain, are exhibited Fig. 43.

Fig. 43.



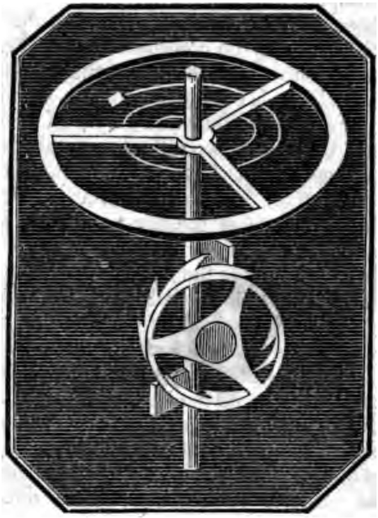
135. The fusee is connected with the great wheel of the watch by means of a ratchet, and in the better class of watches a spring is applied to it, by which it is kept in motion while the mainspring is in the act of being wound up.

136. The watch has five wheels driving four pinions. The second wheel is in the centre of the works, and derives its name from this position. The fourth wheel is a contrate wheel, and the fifth a crown-wheel, called the balance-wheel. The balance-wheel acts upon two pallets attached to a verge, to which it thus gives an oscillating motion. In order to effect the regulation of the watch, a fly-wheel, called the balance, is attached to the verge, and the oscillations of this are confined by a small spiral spring, attached to the verge at one end, and to a fixed point at the other. This spring, from its dimensions, is called the hairspring.

The balance, hairspring, verge, pallets, and crown-wheel, are represented Fig. 44.

137. The rate of a watch is originally adjusted by *altering the length* of the spring between the points

Fig. 44.



to which it is fastened. This adjustment may be subsequently varied by altering the position of the point to which its outer coil is attached. The apparatus for the latter purpose is called the regulator.

138. Were the mainspring and that which controls the motion of the balance of equal strength, the one might control the varying elasticity of the other. But, as this cannot be the case, it becomes necessary to compensate the rate of the watch for the change in the elasticity of the springs, produced by heat and cold. This was at first attempted by means of a curb applied to the hairspring, and acting on the same principle as the gridiron pendulum.

The compensation is now effected in the balance itself, whose weight, and the distance of the circle in which its force may be considered as acting, affects the intensity with which the hairspring reacts. The rim of the balance is cut into segments, each of which is joined to a spoke at one end only. The segments are formed of arcs of two different metals firmly united. As these metals have different rates of expansion by heat, their unequal variation in length will cause the curvature of the arc to change, and alter the distance of the free end of the segment from the axis. In order to give the balance more power, this end of the segment is loaded until the balance can no longer be set in motion by the force of the mainspring, transmitted to it through the train of wheels.

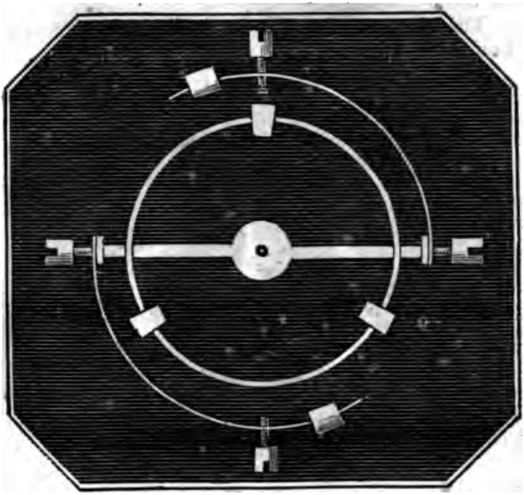
It will be easily seen that the varying curvature of the segments might be made to counteract the varying length of the spokes, and thus make the efficient diameter of the wheel constant. This is not, however, done, for the structure of the balance must, in addition, be made to compensate all the different actions of heat upon the whole works.

A compensation balance, by Arnold, is represented in Fig. 45.

139. The crown-wheel and pallets are equally objectionable as a scapement in the watch as in the clock. A variety of others have, therefore, been proposed, in all of which the contrate wheel is changed into one whose teeth lie in its own plane, and thus the balance-wheel is caused to move parallel to the others.

A scapement which has much celebrity is known by the name of the patent lever. In this, the balance-wheel and pallets are such as have been described in § 130, under the name of the anchor pallets.

Fig. 45.



To the fixed point of these pallets a bar is attached, in the direction of a radius of the balance-wheel; at the extremity of this bar or lever is a segment of a circle-cut into teeth. These teeth catch into those of a pinion which surrounds the verge.

The scapement most frequently used in French and Swiss watches is that *à cylindre*, which usually goes by the name of its inventor, Lepine. It has the form shown in Fig. 46, on page 124.

The best scapement for a pocket watch is that of Duplex, represented in Fig. 47, on page 124.

When the utmost accuracy is required, the chronometer scapement is employed. Of this there are various kinds. The most usual of these is the in-

vention of Arnold, of London, exhibited in Fig. 48, on the opposite page.

This scapement admits of a free or detached motion in the balance.

Fig. 46.

Fig. 47.

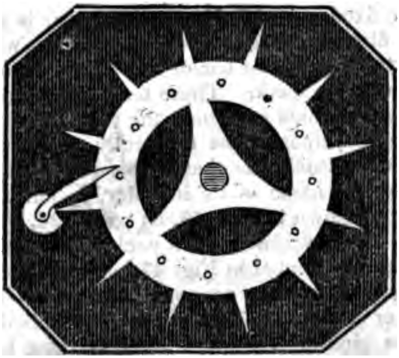
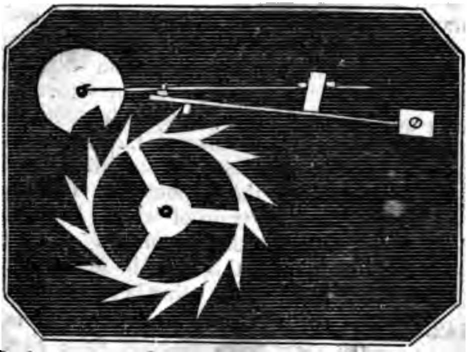


Fig. 48.



To lessen the friction, the ends of the verge, and sometimes of the wheels nearest to the scapement in order, are ground to a point. These points rest in shallow cups of hard stone. In chronometers and watches of the best class, the part of the verge which is worn by the scapement is also frequently made of hard stone.

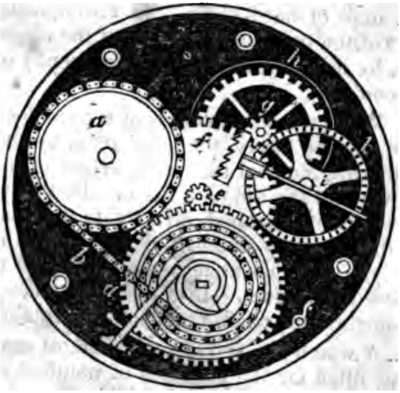
140. When the scapement is of a good description and the balance heavy, the latter may, by the aid of the hairspring, control the irregularities of the mainspring without the aid of a fusee. In this case the great wheel is attached directly to the barrel in which the spring is situated, by means of a ratchet. This is the more usual plan in the Lepine watches and those of Breguet. In English watches and all chronometers, the chain and fusee are retained.

141.. A watch planned to keep the most exact time, and thus fitted for the purposes of nautical astronomy, is called a chronometer. This has one of the scapements appropriate to it, a strong regulating spring coiled in the form of a helix; a compensation

balance; the ends of the axles of the balance and of the more rapidly moving wheels are ground to points, and their sockets bushed with jewels. In order to counteract the irregularities in motion which arise from the fact that a given tooth on either wheel presses with variable intensity upon the tooth of the pinion with which it is in contact, the motion of the scapement is often produced by the direct action of a small spring called the remontoir. The use of the mainspring and the train of wheels is therefore limited to winding up the remontoir. Two such springs must be used in this case, in order that one shall be wound up while the other is in action.

142. The form and arrangement of the parts of a common watch may be understood from Fig. 49, which is a horizontal plan of the works.

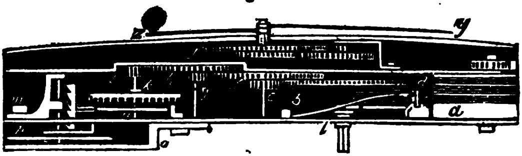
Fig. 49.



a. Wheel containing the spring.
b. Chain.
d. Great Wheel.
e. *Centre Pinion.*
f. *Centre Wheel.*
g. Third Wheel.
i. Axle on the end of which, towards *f*, are seen the Crown-wheel and its Pinion.
k. Contrate Wheel.

A section of the same watch is represented Fig. 50.

Fig. 50.



a. Is the barrel which contains the spring.
b. The fusee and great wheel.
c. Pinion of the centre wheel.
f. Centre wheel.
g. Pinion of the third wheel.
h. Third wheel.
i. Pinion of the contrate wheel.
k. Contrate wheel.
n. Crown wheel.
p. Balance.
y z. Dial work.

143. The construction of a watch is more difficult than that of a clock, and the regulation by hairspring and balance far less accurate in principle than the pendulum. In spite of these obstacles, chronometers have been constructed which have varied little, if any, more than the best clocks from their rates.

144. The cheapness and excellence, even of common watches, is owing to the division of labour. Each different part is the object of a separate trade, and each separate trade is divided into branches, no two of which are exercised by the same individual. The works made in isolated parts are put together between the plates, and sold to the persons who put their name upon them as makers. Up to this time, the number of separate trades which have been concerned in the fabrication of the watch is twelve. The maker afterward employs twenty-one different artists to finish the watch and prepare it for sale, and each of these thirty-three separate branches has its subdivisions of labour.

V.

MACHINES MOVED BY MEN AND ANIMALS.

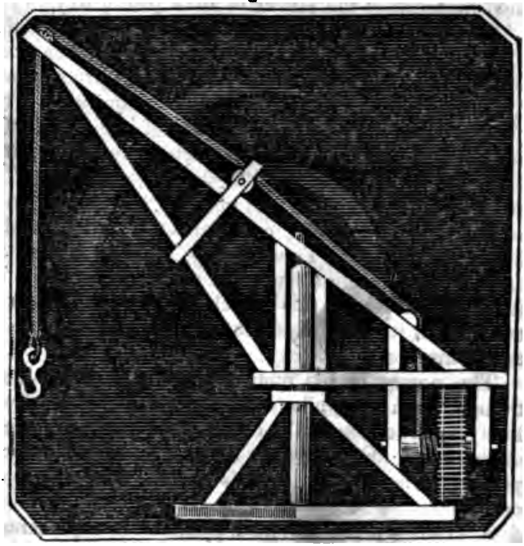
145. The strength of man has found so many aids and substitutes in the great natural mechanical agents, that there are few compound engines to which his unassisted labour is exclusively applied. In many of those capable of being worked by man, whenever long-continued exertion is demanded, the strength of horses or other animals may be more advantageously applied. There are, however, some instances where the strength of man is the only convenient mover under the circumstances to which the machine is subjected. A few of these engines will suffice as an illustration of our subject.

146. The Crane is a machine made use of for raising heavy weights, and, at the same time, changing their position, referred to the horizontal plane, a short distance. The crane is a compound machine, made up of a wheel and axle and a pulley. The accessory parts are the Arbor and the Jib. The arbor is a vertical shaft, having a complete revolution around its axis, except when restricted by position, as, for instance, when the crane is placed against a wall. The jib is a projecting frame attached to the arbor, and revolving with it. The pulley, which may be either single and fixed, or a combination of blocks, is adapted to the extremity of the jib. The wheel and axle is sometimes attached to the arbor, and sometimes placed on a separate basis. The crane may be portable, or, if not portable,

may have no other support than its pressure on its own base. In such a case, the machine must be so constructed that even when loaded with the heaviest weight it is capable of lifting, the line of direction of the centre of gravity shall fall within the base.

A crane of this description is represented in Fig. 51.

Fig. 51.



The wheel and axle takes, in the above figure, the form of a windlass. This may be worked by men taking hold of pins adapted to its circumference. The wheel has also been made hollow, and stairs formed upon its inner circumference. Men walking upon these steps cause the wheel to turn by their

weight. A better method consists in forming the steps on the outside of the wheel, and adapting a platform at the level of the horizontal diameter of the wheel, whence men may step upon its circumference. This is one of the most advantageous modes of applying human strength. A man working upon it, besides overcoming the friction of the engine, has exerted, for ten hours per day, eight tenths of the assumed measure of the power of man (see § 31).

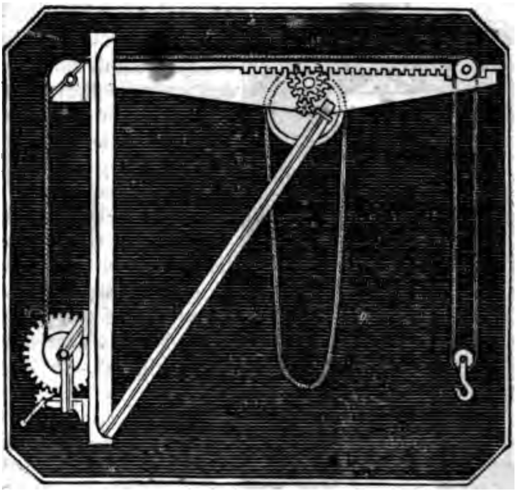
When the crane is placed within a building, the top of the arbor may be supported by a beam, or from one of the walls. In this case no precautions for balancing its centre of gravity are required. The jib may now take the simple shape of a gibbet formed of a horizontal beam supported by a diagonal brace. In this form the pulley, instead of being fixed at the extremity of the jib, may be adapted to a small carriage moving on a railroad laid upon the horizontal beam. This carriage may be moved to and fro, by passing a chain over a wheel adapted to it for the purpose; this wheel has another, cut into teeth, upon its axis, which catch into a rack laid upon the beam.

The power of the engine may be increased, although, as in all similar cases, at the expense of velocity, and, consequently, of time, by cutting the wheel of the wheel and axle into teeth, and driving it by a pinion. The pinion itself is turned by a winch or crank.

A crane with these modifications is represented in Fig. 52.

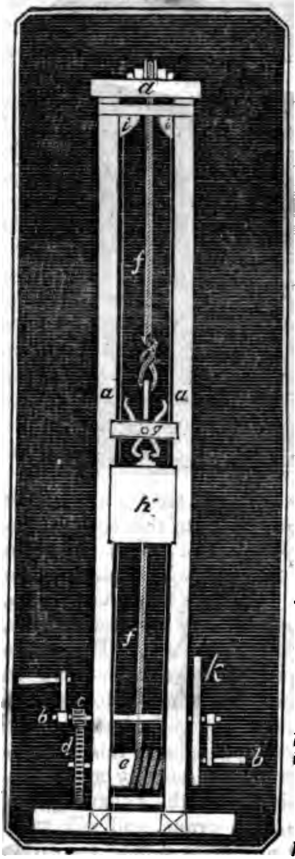
147. The Gin or triangle is also composed of a wheel and axle, or pulley. Its accessory parts are a tripod of wood, and a hook whence the pulley is suspended. The wheel and axle is usually worked, like a ship's windlass, by handspikes passed into holes cut in the axle for the purpose.

Fig. 52.



148. In building walls of heavy stones, cranes are occasionally used; in some cases of this sort, an engine called a Derrick is employed. This is also a combination of a wheel and axle with a pulley. In some instances it takes the same form as the gin, in others the pulley is supported by a gallows frame, to which the wheel and axle is attached. This frame is supported by two ropes or stays, by hauling on one of which and slackening the other, a stone raised parallel to the face of a wall may be laid on the wall itself. A still more perfect apparatus of this description, called the Boom-derrick, has recently been introduced in this city. This unites the advantages of the derrick with those of the crane, and will raise and set down its load at any point within the circle of which the boom is the radius.

Fig. 53.



149. In the Pile-engine, a heavy weight is slowly raised to a considerable height, and then suddenly discharged upon the head of a pointed beam which is to be driven into the ground. It is usually composed of a wheel and axle combined with a single fixed pulley. The form employed in the hydraulic works of the city of New-York is represented in Fig. 53.

a a a. Frame.
b b. Cranks or winches to which the power is applied.
c. Pinion on the same axis with the winches.
d. Wheel driven by the pinion *c.*
e. Barrel on the same axis with the wheel *d.*
f f. Rope by which the ram and follower are raised.
g. Follower, having a weight sufficient to return the rope after the ram has fallen. It contains a pair of shears, which close by their own weight upon a hook or staple forming a part of the ram.
h. Ram.
i i. Blocks or cheeks with curved surfaces, on entering between which the shears are opened and release the ram.
k. Fly wheel.

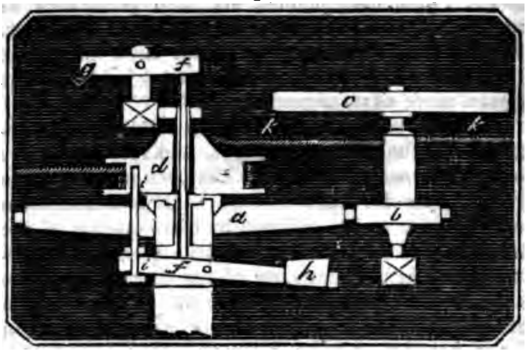
The treadwheel furnishes a better mode of applying human strength to this engine than the winch. By a direct comparison made by Captain Turnbull on the Potomac aqueduct, six men performed as much work with the former as eight with the latter. Major Smith, U. S. Engineers, has used an engine in which the men tread upon a vertical ladder, which is even more advantageous.

In great hydraulic works, as in establishing foundations for the piers of bridges, and for wet or dry docks, the strength of horses has been substituted in driving piles for that of man. This substitution might appear to be difficult, in consequence of the risk to which the horses would be exposed of incurring injury at the moments of the discharge of the ram and the attachment of it to the follower. The return of the follower without reversing the motion of the horses, or an acceleration that will injure the machinery, also requires to be provided for. These several difficulties have all been obviated in the pile engine of Vauloue. This is also remarkable for having been one of the few engines which have come perfect from the mind of the inventor, the original machine having every part necessary to its performance, and having received no improvement except in workmanship and materials since it was first employed in the structure of Westminster Bridge in 1732.

The ram and follower, with the gallows, pulley, and inclined cheeks, are similar to those of the engine just described. The shears of the follower are of more perfect structure, and have rollers on the extremity of their arms, in order to lessen their friction on the cheeks. The wheel and axle has a vertical axis, and is represented in Fig. 54.

The action of this engine will be understood by the description of this figure.

Fig. 54.



a. Great wheel, to the axle of which the horses are harnessed by means of horizontal bars.
b. Pinion.
c. Fly-wheel on the same axle with the pinion. This is of such weight, and opposes so much inertia to the action of the horses, that the attachment of the follower to the ram is not attended with sensible resistance, and the weight of the latter only produces a gradual diminution of the speed of the horses. The velocity of the fly-wheel is again diminished gradually when the ram is discharged.
d. Drum on which the rope *e* is wound; this rope, after having its direction changed by two pulleys, is attached to the follower.

The axles of the drum and great wheel are hollow, and a spindle, *f f*, passes freely through them. This spindle is pressed against the end of a lever *f g*, by a weight acting upon a lever *h f i*. The same weight acts upon a pin *i i*, by which the great wheel *a* is attached to the drum *d*. To the opposite end of the lever *f g*, cords are attached, which proceed to the top of the frame within which the ram and follower move. When the latter has reached its high-

est position, and immediately after the ram has been discharged, it presses against these cords so forcibly as to raise the end of the lever *f g*, to which they are attached, and thus forces down the other end *f*. In this way the spindle *f f* is made to act on the lever *i f k*, in such manner as to draw the pin *i i* from the drum *d*. The latter being thus detached, the weight of the follower is sufficient to turn it backward, and the follower begins to fall. In order to prevent the acceleration of the descent of the follower, a fusee is formed on the top of the drum *d*. Upon this fusee a cord *k k* is coiled while the ram is raised. To this cord a small weight is attached, that acts at distances from the axis which increase as the cord uncoils itself, and thus opposes the acceleration of the follower.

The selection of machines we have now made will suffice as instances of the manner in which the strength of men and animals may be employed. As respects the use of the latter as a prime mover, wheel carriages furnish an instance of more frequent and general application. The principle on which the use of these depends, and the rules for constructing the roads on which they move, are of sufficient importance to entitle them to be considered under a separate head.

VI.

OF WHEEL CARRIAGES AND ROADS.

150. When the strength of an animal is applied to draught, the force exerted is measured in terms of a weight raised perpendicularly upward. In the case of a horse, the most advantageous exertion of his strength has been settled (§ 30) to be that of lifting a weight of $186\frac{2}{3}$d lbs. with a velocity of $3\frac{1}{3}$d feet per second for a day's work of eight hours' duration. This application of force will move a much greater weight along a horizontal plane, for the resistance is no longer the weight itself, but the friction produced by the pressure of the weight upon the plane over which it is moved.

151. This friction may be diminished by causing the body which is to be drawn to roll instead of sliding; by laying the body upon rollers; and, finally, by placing the body upon a wheel carriage. The latter method possesses advantages in respect to draught, growing out of two causes:

(1.) The friction of a well-polished axle is no more than $\frac{1}{10}$th of the pressure to which it is subjected.

(2.) The wheel is caused to turn around by the friction of its circumference upon the track. The place where these touch may therefore be taken as the point of application of the force, and a mechanical advantage is thus gained, upon the principle of the lever, in the ratio of the radius of the wheel to the radius of its axle.

If we take for this ratio 1-10, which is a proportion frequently found in practice, the force of a horse exerted in draught upon a well-constructed wheel carriage ought to be

$$186\tfrac{2}{3} \times 40 \times 10 = 74{,}666\tfrac{2}{3} \text{ lbs.}$$

or about thirty-three tons.

The actual advantage gained upon the best roads and with the most perfect carriages, does not often exceed one twentieth part of this, and it is usual to state the force of a horse, in drawing a carriage upon the best level road, at no more than 20 cwt. of efficient load, upon a carriage weighing 10 cwt. The reasons of this vast discrepance are:

(1.) The friction of axles, in practice on a large scale, is greater than that inferred from experiments on a small scale.

(2.) Besides the friction upon the axle of the wheel, a sliding friction takes place between the hob of the wheel and the shoulder of the axle on the one hand, or the linchpin on the other.

(3.) A friction takes place between the faces of the wheel and the materials of the road.

(4.) Inequalities on the road are continually disturbing the regularity of the progressive motion, and destroying the motion previously communicated to the carriage.

The effect of the last cause will be better understood when we consider that, when the carriage is first set in motion, it must derive from the prime mover a quantity of motion which may be estimated by the product of the measure of the resistance into the velocity. This impulse having been once given, the carriage would tend to go on in a straight line with a uniform velocity. If, then, the motion on the road were truly in a straight line, no other force would be necessary than as much as would equal the friction. But if, from inequalities in the road, the velocity be checked at irregular intervals, and the wheels be caused to deviate from their proper course, the prime mover must not only overcome the friction, but restore the quantity of motion lost from this cause.

152. Were we to have reference merely to the me-

chanical advantage which wheels possess, it might be inferred that, with a given diameter of axle, the greater the diameter of the wheel the better. This is the case, whether we consider their effect in overcoming friction, in surmounting obstacles, or in depressing them. If, however, the obstacle is to be removed, the less the diameter of the wheel the better; but it rarely happens that this kind of action is to be desired. The height of the wheel is, however, limited by the direction of the draught.

A horse may be considered as exerting his draught very nearly in the direction of his traces, or in a line drawn from a point in his breast to the axis of the wheel. When this line is horizontal, the whole of the force is applied to draught; when the draught is directed upward from the axle, a part of the force of the horse is wasted in an attempt to lift a part of the weight of the carriage; and when the axle is higher than the horse's breast, a part of his force is exerted in producing a pressure upon the axle, by which the friction is increased. It is, however, said that, upon a smooth and level road, the mechanical advantage gained by an increased diameter of the wheel is for a time greater than the loss by the increased friction; and that wheels, whose axle is a little higher than the breast of the horse, have been used with success. In all usual cases, an axle a little lower than the point in the collar to which the traces are attached is most advantageous. This is more particularly the case on hilly roads, where, in rising, a part of the force must be applied to overcome the gravity of the load, and in descending, its spontaneous velocity is to be checked. A carriage with low wheels is also less liable to be upset.

153. A horse, in drawing, leans forward upon his *collar, and would* fall were the resistance to be sud-

denly removed. He therefore acts not only by his muscular force, but also by his weight. For this reason, in drawing heavy loads, horses of a large breed are found more valuable than smaller ones, even of equal muscular strength. For agricultural purposes, and for transportation on turnpike roads, it is unwise to substitute, as has been done in the State of New-York, the blood horse for that of Flanders. From this error the Esopus breed of horses, one of the most valuable known, has nearly become extinct. Blood horses, on the other hand, are better for travelling with speed, and are considered to possess greater powers of endurance. They also are capable of recovering their strength after a degree of exhaustion which would be fatal to most other races.

Their superiority in the latter respect over our American races is not, however, so great as has been generally imagined. Pennsylvania possesses a breed of horses, said to be originally derived from that of Esopus, but improved by crossing with those of Hanover and Lancashire, which sustains extremes of cold far better than the blood horse, those of heat equally well, and which has great powers of endurance. These horses, when used upon the road, are rarely sheltered, and may be seen sleeping upon the snow in the streets of Philadelphia in the coldest weather. As a proof of their powers of enduring fatigue, we have it on the authority of a general officer of great distinction, that five hundred young horses of this breed were purchased for the purpose of draught and mounting flying artillery at the commencement of the late war with Great Britain, and that, at the end of the year, not a single horse had been lost from any other cause than wounds received in action, although the service had been one of extreme fatigue.

For the same reason that the heavy horse is best adapted to agricultural labour, oxen have been found of great value in all cases where a small velocity is sufficient. This animal, however, has less power of recovery from fatigue than the horse, and this power is exhausted after its full growth has been reached. It has therefore been recommended, that oxen be worked no longer than they continue to grow, and be then fattened for slaughter.

The power of a horse in draught is not only aided by his own weight, but may be increased when he is loaded with an extrinsic weight. For this reason, a horse will draw more in a carriage with two than in one with four wheels; for, in the former case, a part of the weight presses on his back. It is even a practice with the drivers of carts, when a horse meets an obstacle over which he cannot force the wheel, to mount upon his back, and the obstacle may in this case be surmounted.

Upon this principle we may explain a fact long remarked in the artillery service of Europe, namely, that the horses which are ridden by the drivers are always in the best order, and are more capable of enduring fatigue. The same fact has been remarked in posting on the continent of Europe, where the horse mounted by the postillion is always found to be fattest. This observation, however, is not true on the postroads of England, owing to the difference in the character of the roads. In the latter country the roads are so good that the strength of the horse is rather applied to obtain velocity than to overcome friction; and in this case a load is disadvantageous.

154. The advantage of carriages with two wheels ceases when the weight is so great as to require more than one horse for its draught; for it is by no *means easy or* convenient to attach two or more

horses to a two-wheeled carriage in such a manner that each shall bear an equal part of the weight. This has indeed been attempted in the agricultural carriages of Flanders, which are often of the form of a curricle. Such carriages, however, can only be employed in a level country.

In order to extend the advantages of two-wheeled carriages, horses have been occasionally so trained that a single driver can manage five or six carts. This is done by the farmers of Scotland, who boast much of the superiority of this method, and of the good construction of their carts. The cart used in the city of New-York is, however, fully equal to that of the Scotch agriculturists, and is superior in most respects to the drays used in Philadelphia and Baltimore, and to the trucks of the eastern cities.

Carts are also advantageously used when the drivers can be employed in loading them, as, for instance, in removing earth for regulating streets, and in excavation and embankment for railroads and canals. The facility with which they are unloaded also gives them great advantages in such cases.

155. In applying more than a single horse to draught, they ought to be harnessed in pairs, and not *tandem*. In the latter case, the wheel-horse is exposed to much additional fatigue. When harnessed abreast, no more than two can be conveniently thus placed, as the inner horses will be distressed by the pressure of the others.

In the transportation of heavy weights for great distances, wagons drawn by four, six, or eight horses, harnessed in pairs and driven by one person, are most advantageous.

156. In wagons and other four-wheeled carriages, the fore-wheels are made of less diameter than the

others, in order that they may pass beneath the perch in turning. For all other reasons, such difference is objectionable. The defect of the smaller wheels may be remedied, in some degree, by loading them with a proportion of the weight, as much less than that borne by the hinder wheels as the diameter of the one is less than that of the other.

157. It is important, in harnessing horses abreast, that they should be exactly matched in gait. Equality of strength would also be of great value, were it not that it is possible, by placing the fulcrum of the bar on which they draw, at a distance from the points to which the swivel-trees are attached, inversely proportioned to the respective strengths of the horses, to bring them to a condition of equality.

158. The spokes of wheels are not situated upon a plane surface, but are usually adapted to the hob and fellies in such manner as to lie in the surface of a cone of small altitude. Wheels of this figure are said to be dishing. As roads have an inclined or curved section, this method is often advantageous, inasmuch as the spoke on which the greater part of the weight rests will be in its position of greatest strength when the action upon it is most intense. The axles are also usually inclined downward from their shoulders. This construction was probably adopted for the same object as the dishing wheel, but may be said to be objectionable for every reason.

159. In carriages loaded with heavy weights, the face of the wheels should be broad. Nothing is lost by this construction, even upon hard and smooth roads, for the friction does not increase with the surface within the limits to which the breadth of wheels are restricted. In soft roads and those cut into deep *ruts, broad wheels* possess a manifest advantage.

Carriages with broad wheels also, so far from injuring roads, tend to maintain them in repair.

In England, in spite of the opposition of wagoners, the wheels of heavy wagons are required by law to have a breadth of fourteen inches, and this regulation has not only lessened the cost of keeping roads in repair, but is at length admitted to have a direct beneficial influence upon the profits of the wagoners themselves.

160. Springs, which were originally introduced merely for the ease of persons conveyed in carriages, are found to give to horses the power of conveying heavier loads than they otherwise could. In producing this effect, they permit the weight of the load supported by them to act upon the same principle that a fly-wheel does (§ 17).

161. The roads upon which wheel-carriages travel ought to be as smooth and equable as possible, in order that less effort may be necessary to continue the motion at a given velocity. They ought also to be hard, in order that the wheels may not penetrate and form ruts. On the other hand, too hard a material is apt to injure the feet of the horses, which are rapidly destroyed upon a stone road. In spite of the latter objection, stone broken into fragments is the most favourite material for road-making. In this form it is known by the name of metal. The stone used for the purpose should not be liable to decomposition by the weather, nor to be readily ground to powder. A compact limestone is, perhaps, for a combination of advantages, the best road-metal. The largest fragments of stone should not exceed six ounces in weight, or they may be regulated by passing them through a ring two and a half inches in diameter.

A native gravel, whose fragments are not liable to

decomposition or too rapid a wear, is the next best material for roads, and there are cases in which it is preferable, particularly when it has the property of binding, or uniting into a continuous mass. When gravel is employed, the largest fragments should not exceed one inch in diameter.

These materials may be laid upon any firm soil after it has been dressed to a proper figure. In performing this operation, after removing the vegetable mould, the natural earth should be as little disturbed as possible, for earth recently moved is increased in bulk about one ninth. This increase will gradually be lost by the settling of the earth, but so much of it as is within reach of the frost will be disturbed at each change of season. For this reason, the use of the plough, which is so favourite an instrument in making and repairing the roads of the United States, is altogether objectionable. If embankments are necessary, they must be allowed to settle before the road-metal is laid upon them. It is better, except where the soil of the ground in which the road is to be formed is itself gravel, to make the cross section of the surface of the ground on which the road is to be laid a level line, and to give the road its proper figure by the distribution of the material.

The average thickness of the road-metal on a new road need not exceed six inches, for it is better to reserve any greater quantity for repairs, and particularly for filling up ruts as often as they are formed, than to lay it on at first. The metal ought to be laid on without any attempt at arrangement, in order that the pieces of different sizes may be mixed indiscriminately. In this country it has been usual to put upon roads as much as three or four feet of broken stone; but this involves a useless expense. It has also been usual to admit of stones of large size, and,

in order to remedy the defects of such masses, to cover them with gravel and sand. In cases where gravel alone has been used, it has been carefully sorted, so that the layers should be composed of pebbles decreasing in size from the foundation upward. This method not only involves a large expense, but is vicious, inasmuch as the heaving of the road when wet, and particularly in alternations of frost and thaw, will infallibly bring the largest pebbles or fragments of stone to the surface. This rule, however, does not apply where the larger fragments are united by mutual pressure into the form of a pavement.

Upon soft ground, as in meadows or rich alluvial soils, paved roads are the cheapest, and they are in all cases the most durable. They, therefore, are universally used in cities; and upon the Continent of Europe, nearly all the great roads are paved. The best of all roads are probably those constructed in England upon the plan of Telford. These roads have for their basis a pavement of rolled pebbles laid in coarse sand. The larger axes of these pebbles are placed upright, and if either end be more pointed than the other, the sharper end is set uppermost. The stones of least dimensions are laid near the sides of the road, so that a convex form, where required, may be given by the prominent points. The intervals between the stones are filled up with road-metal, and the whole covered with that material or gravel to the depth of four inches.

Of the different rocks, those are to be chosen for road-metal which are not liable to decomposition or desquamation. Compact limestone always possesses this property, and is among the best of materials. Some of the greenstones and granites, as well as gneiss, are also well adapted to the purpose. Of the

rocks within our own reach, a graywacke, which is abundant on the banks of the Hudson below Albany, is an excellent material; the greenstone of the outer ridge of the Palisades, which begins at Weehawken, is too liable to decomposition, as is the Jersey sandstone; but the greenstone of Bergen and Newark mountain is desirable. The mica slate of our island is very easily decomposed, and too soft. Of pebbles, an excellent variety, principally quartz, is found in Monmouth county, New-Jersey, where, although obtained from a decomposing conglomerate, it is known as sea-beach gravel.

162. The least breadth of the carriage-way of a road should admit of the passage of two carriages, or be 15 feet. It may not be necessary to pave, or form of metal, more than half of this breadth, except at intervals of about 100 feet, where the whole breadth should be properly laid, in order that carriages may pass each other when the road is affected by thaw and frost. On much-frequented roads, the breadth should be 30 feet, so as to admit four carriages abreast; no more than half of this, say the middle portion, need be constructed on Telford's plan, or even laid with metal, except in the immediate vicinity of large cities; and in the latter case the road ought to be 45 feet in width.

Besides the carriage-way and ditches, all roads ought to have a path on one, if not on both sides, for foot-passengers; this should be laid with gravel. It is to be regretted that this rule, so important for the public convenience, is wholly neglected in this country.

163. The cross section of a road must, on the one hand, be of such a character as will permit the surface water to run over it to a ditch on the

side. On the other hand, this slope must not be steep in any part, otherwise carriages may be exposed to the danger of upsetting, and the lateral friction, whether of the fellies or of the axles, will be much increased. On roads where there are gentle slopes of small inclination, the cross section of the surface might be a level line, were it not that the road would be liable to be washed. A road is also liable to injury from the latter cause, if the curve of its cross section rise too rapidly from the vicinity of the ditch.

It is usual to make the cross section of roads a convex curve, not differing much from a circular arc; but this figure is disadvantageous in almost any case, and is in some wholly inadmissible.

164. There are three principal cases in the determination of the figure to be given to the cross section of roads:

(1.) When a road nearly level lies on ground which is level in the direction of the cross section. In this case a ditch is to be formed on each side of the carriage-way, whence the metal should be laid so as to form two planes of equal inclination, rising from the ditches towards the middle of the road, where the two planes are to be united by a gentle curve.

The inclination of these planes must not exceed 1 foot in 20, or cause a difference of level between the crown and the edge of the ditch of more than 9 inches in a road of 30 feet in breadth. In narrower roads, the inclination is to be the same, and the difference in level diminished in proportion to the diminished breadth.

(2.) On side-lying ground, the cross section of the road should be a line of uniform inclination of not more than 1 foot in 20 from the outer edge of the road towards the higher ground; and there should

be but one ditch, lying between the road and the rise of the hill.

(3.) In a hollow-way the road must be inclined in the direction of its length, and it is generally better to have but a single ditch, formed in the middle of the road, towards which it is inclined equally on each side.

Where a road lies between two ditches, as in the first of the three cases, the two inclined surfaces, even if permitted to meet at an edge, will be speedily united, by the action of the carriages which travel it, by a continuous curve. But roads having for their transverse section a convex curve are in all cases objectionable, and are to be absolutely excluded on side-lying ground and in hollow-ways. In our country, from a misapprehension of the meaning of the word turnpike, no other mode of forming roads has been usually practised than to heap them up in the middle by the plough and scraper. The convex curve, thus formed is produced with increasing declivity, to the very bottom of the ditch.

Such roads have too little inclination at the crown, where water lodges and ruts are formed. They compel the carriages to confine themselves to the ridge, by which the wear is restricted to a narrow track; they cause danger to loaded carriages attempting to pass each other, except on the widest roads, and, by the increase of the lateral friction, materially diminish the loads which can be drawn by a given force. In some of the roads in the United States, although wide enough for four carriages, it is unsafe to attempt to pass one which occupies the crown of the road.

The scraper, by bringing to the summit of the road the matter which has been washed into the ditches, *replaces the* worst part of the material in a deterio-

rated state, and it may be questioned whether it be possible that we shall ever have good roads in this country until this instrument be abandoned. Instead of employing it to replace the soft matter from the ditches, that ought to be carefully removed from the road altogether, the wear of the road should be replaced by fresh metal, and the ruts filled up with the same. A single cart and driver, continually employed in carting gravel, will keep miles of country road in good order.

165. It is an excellent plan to pave the ditches of roads, and particularly with flag stones when they can be procured. The water which collects in these ditches must be carried off from time to time by cuts through the footpath or bank of the ditch, and in some cases it becomes necessary to pass this water beneath the road by means of culverts. These are always necessary upon side-lying ground, where it is particularly important that no large stream of water shall form, and where the water is thrown by the cross slope of the road towards the rise of the hill, a position whence it cannot escape except by a culvert, or by forming a rapid stream upon the surface of the road.

166. The best of all roads for rapid summer travelling is composed of a native gravel of such character as to bind, although this substance is far from durable under the action of heavy carriages. This may be known in its own beds by the difficulty with which it is excavated. Such gravel can be found in almost all countries, except those which are wholly composed of soft alluvium. It also forms the best basis for a paved road. Whenever it can be obtained conveniently, the loose superficial matter may be removed to a depth of six inches, and replaced

by a bed of such gravel of the thickness of a foot. Upon the middle of this to the breadth of 15 feet in a great road, or of $7\frac{1}{2}$ in a by-road, a double or single way of broken stone, or of pavement covered with broken stone, is to be constructed, and the slope each way, from this to the ditch left in the excavation, completed with the gravel. In this way a good summer, and also a good winter road will be united. When the soil is a native gravel, the construction of the road may be effected by the plough and scraper; and this is the only case in which they should be used, except for removing the vegetable mould, and for levelling where embankments are indispensable. These implements are of great value, but may be productive of injury in the hands of ignorant persons, who disturb unnecessarily the foundation of the road.

Except when the basis of the road is a pavement, a heavy roller may be used to great advantage in compressing the materials and causing them to bind.

167. The slope of roads in the longitudinal direction depends in some degree upon the nature of the country, but it is generally possible, by a small increase in their measured length, to obtain such a slope as may be most advantageous for travelling upon them. This slope may be best determined by ascertaining at which inclination a carriage will be supported upon the road by friction. Experiments make the friction vary between $\frac{1}{45}$th and $\frac{1}{10}$th of the weight; and on well-laid pavements, such as we shall hereafter speak of, it has been reduced as low as $\frac{1}{68}$th. It will, in all ordinary cases, be sufficient for practical purposes to take the friction at $\frac{1}{40}$th of the weight; and if a road be laid out with a slope of 1 foot in 40, or making an angle of $1\frac{1}{2}°$ with the horizon, it will be under advantageous circumstances,

for there will be little need of diminishing the load a horse is employed to draw upon it; and he may, if applied to obtain speed, move with equal freedom in either direction.

Any greater inclination is to be avoided; for the force of the horse must, at such inclination, be applied not only to overcome the friction, but to lift a part of the weight. The strength of a horse, also, is much diminished by moving on any other surface than a plane nearly level; and at an inclination of 45° he ceases to be able to move even his own weight upward, and falls in descending. In reducing the slopes of roads to the above limit of $\frac{1}{40}$th, it is usually more economic to do it by making the road curve so as to adapt itself to the ground, than to attempt to make it straight by cutting and filling. As a general rule, then, a straight line is to be avoided for a road, except in a country absolutely level, or with a uniform slope in one direction, neither of which usually occur in practice. By making a road curve in such a manner as to secure the requisite slope, the effective length need seldom be much increased, nay, may often be lessened; for the true distance by a road is not its length as it would be projected on a map, or measured in horizontal lines through the air, but will be determined by the number of turns a wheel must make in passing over it. A road which is continually bending on each side of its mean direction, in order to pass nearly level over an undulating surface, is not only the easiest for rapid travelling and for the transportation of heavy loads, but is far more agreeable to the traveller from the variety of scenery it furnishes. The practice of the earlier settlers in our country led to the choice of such locations for their roads, and it was an unlucky circumstance when the belief that a straight road must be

the shortest, led to the abandoning of many of the ancient routes. Our turnpikes are, in general, ill laid out, from its having been adopted as a principle that a road should be straight provided the slopes upon it did not exceed 5°. This rule was borrowed from the extreme slope allowed in the road of the Simplon, and thus it has happened that many roads in districts whose mean surface is level, and in which a level road might have been laid out, are continually rising and falling, at an angle which was only tolerated in crossing a range of mountains of more than double the height of any in the United States.

To compare together straight and curved roads in an undulating country, we shall assume a case. If the geographical distance between two points in a direct line be twelve miles, and if a straight road between them can only be constructed by means of slopes of 5°, while a level road may be made by increasing the distance to thirteen miles, a wheel will make the same number of turns on both roads, and their efficient length will be actually the same. But they are far from equality in other respects. On the level road, a horse before a light carriage may trot the whole distance, while on the inclined road he must walk, unless the dangerous practice be adopted of galloping down the hills. On the level road the horse will draw the maximum load, say 35 cwt., while on the inclined road he will not draw more than half that weight. On the other hand, although a road may be curved with advantage, it must not change its direction suddenly, and no curve should be admitted of a less radius than 100 feet.

168. In conformity with the foregoing principles, the following rules may be adopted for laying out *new* lines of road:

(1.) Between two points of nearly the same level,

and in an undulating country, a route is to be sought, which, if not actually level, shall admit of no slope greater than $\frac{1}{40}$th; and it will be more economic to do this by curving the road upon the natural surface, than to attempt to level it by excavation and embankment for the purpose of obtaining a straight road.

(2.) Between two points at different levels, a route is to be sought which will give a uniform slope from one point to the other; or, in other words, the road, when developed, should be a plane of constant inclination. This inclination, except in extreme cases, as in ascending or descending abrupt and continuous ranges of mountains, must not exceed $\frac{1}{40}$th.

(3.) When a ridge intervenes between the two points, the lowest accessible gap or break in the ridge is to be sought, and the road must be laid out from it in both directions according to the foregoing rule.

It will be easily seen, that many of the turnpike roads in the United States sin against the foregoing rules; they are, besides, defective from a badly chosen figure for the transverse section, and from the large size of part of the material which has been used. Although the latter may have originally been placed beneath, it has in all cases made its appearance at the surface. The narrow wheels which are permitted in carriages carrying heavy weights, are also continually cutting our most frequented roads into deep ruts, and the prejudices of wagoners seem to preclude any hope of excluding this cause of continual destruction.

Taking all things into account, we are compelled to admit, that, with very few exceptions, the roads of the United States, when considered in respect to their cost, the general facilities of obtaining good materials, and the small elevation of much of our conti-

nent, are the worst in the world. From this general rule there are, no doubt, exceptions, and these are more usually in the most difficult positions, where native genius has thrown off the false rules which had been imposed. Some of our road-makers, as, for instance, the person who originally laid out the national road from Cumberland, seem to have been of opinion that 5° was not a maximum, admissible only in an extreme case, but that such a slope was to be sought in all cases.

A most mistaken notion has been entertained by road-makers, namely, that a horse, by exercising different muscles in rising and descending, travels with less fatigue upon an undulating road. This is denied by physiologists; and, even were it true, the diminution of load or of speed would far more than compensate any gain in the number of hours the animal could work per day.

Among the best specimens of laying out roads which we have seen, are: 1st. One in Scotland, between Dumfries and Castle Stuart. The geographical distance between these places is sixteen miles, and the road measures twenty miles. By this increase the slopes have been reduced to 1 foot in 100, with the exception of two at the summit of the ridge, where they do not exceed 1 foot in 40. 2d. One in Putnam county, New-York, leading eastward from Cold Spring. 3d. The road laid out by Mr. Crozet, from Winchester, Va., to the South Branch of the Potomac. 4th. The new line of the national road, from Cumberland westward.

169. Pavements are not only advantageous as a basis for roads, but are absolutely necessary in the streets of cities. Any other earthy material wears too rapidly to bear the continued traffic, gives rise to much dust, and becoming mixed with filth, pre-

vents the streets from being properly cleansed. Such pavements are, in our country, made of rolled pebbles. These have the advantage of forming a durable road, and one which may be easily kept clean. It is, however, disagreeable in the motion it gives to carriages, and is not as easy to draught as a well-made gravel or Macadamized road.

The pavements of London and Paris are made of cubical or rectangular blocks of hammered stone; in the first city, of granite, in the second, of the silicious limestone of Fontainebleau. These are laid in courses across the street, and so as to break joint in the direction of its length. Such pavements also cause a disagreeable motion in carriages, and continually check their motion at the joints.

In the streets of Pisa, in Italy, the best form of stone pavement which has yet been planned was originally introduced. The street is divided into spaces corresponding to the breadth of a carriage. In each of these, ranges of blocks of stone are laid lengthwise, at distances fitted to receive the wheels of a carriage. The space between them is filled with a pavement of rounded pebbles. Thus the horse has a firm foothold, while the resistances are materially diminished. This method has been imitated in Milan and other Italian cities; it has also been copied on the Radcliffe Highway, London.

Pavements are usually laid in coarse sand, upon a bed of gravel. It would, however, be better to lay them in water cement, by the aid of which they would become almost everlasting. Such was the method used by the Romans in their great military roads. Of these, parts of the Appian Way remain almost perfect, after a lapse of more than twenty centuries. This road has for its basis a bed of cement mixed with chip stone. This is covered with

a second bed of cement, mixed with small pebbles, which admits the stones to be bedded until their upper surfaces are of the same height, and yet yields them a firm support. The stones are polygonal masses, obtained from the columnar rocks of neighbouring volcanic formations, and are chosen in such manner as to fit each other as closely as possible.

170. A wooden pavement, formed of blocks of wood of the shape of a six-sided prism, has been used for ages in Russia, and has recently been introduced, in an improved form, in some of the streets of the city of New-York. These blocks are laid in such manner that the wear takes place on the end grain of the timber, and, so far as wear by carriages, ease of transportation, and cleanliness are concerned, has given universal satisfaction.

The last-mentioned method might be practised in those parts of the United States which are still covered with forests to great advantage. In these districts, roads formed of logs laid across the road are much used; and, where sawmills can be erected, the preparation of blocks for the purpose could not be attended with great expense. Roads composed of round logs, although rendered necessary in the soft soils which are frequent in forests, are the most disagreeable of any to the traveller, and do not admit of horses drawing a full load. The objection to the pavement with wooden blocks is its comparative want of durability. The timber is under circumstances the least favourable to its preservation, and it has, in consequence, been found necessary, in the experiments which have been made in New-York, to replace many of the blocks annually. This objection may, however, be obviated, by saturating the wood by a process recently invented, which promises to render the duration of wood indefinite.

The substance with which the wood is saturated in this process is coal-tar, or native bitumen.

171. A material called asphalte or asphaltum, but which is properly a peculiar kind of bituminous lime-stone, has recently been introduced in France. This substance is reduced to powder, and mixed with a fused bituminous substance. The liquid mixture may be mingled with a considerable quantity of gravel, in which case it is used for sidewalks, or with road-metal if intended for carriage-ways. For the first object there is no doubt of its success, if it can be afforded at a sufficiently low price; for the latter purpose its value has not been sufficiently tested.

VII.

RAILROADS.

172. The want of continuity in the motion of a wheel carriage, the lateral friction upon the road, and that arising from penetration in soft materials, may all be obviated by causing the wheels to move upon parallel bars laid in the direction of the road. In this way also it is possible to improve the structure of the carriage, and give it greater nicety of workmanship.

Railroads were first introduced in the mines of Durham county, England, and took their rise gradually, from accidental causes. It had been usual to lay parallel rails in mines, on which carriages with two wheels were moved by men. In the great works which these mines required, the galleries were enlarged, until carriages drawn by horses were substituted. It was now found that a horse could draw much more in a cart moving upon rails than he could upon a common road. The rails were, in consequence, extended from the mines to the wharves at which the coal is shipped. The rails in this early instance were made of wood, a flanch was applied to them to prevent the wheels of the cart from slipping off the rail. In order to lessen the wear of the wood, the rail was covered with a plate of wrought iron. In this state railroads remained for a century, and were confined to the district in which they were originally introduced.

As timber became scarce, and the price of cast

iron became low in England, the latter material was substituted for the former. The rails were cast in lengths of about three feet, with a flanch on the inner side, and were supported at their junctions on pillars or blocks of stone. In this form the way was called a tram-road. Originally intended for the use of common carriages, it was soon discovered that carriages expressly constructed for the purpose were more advantageous. In these, as there was no necessity for turning, the wheels were all made of equal heights; as there was no difference in the height of the rails on opposite sides of the road, the wheels were not made to dish, the axle-tree was made straight from end to end, and was made to revolve with the wheel. In these tram-roads, the quantity of weight moved by a horse was increased fivefold.

The next improvement consisted in removing the flanch from the rail, and placing it on the inner side of the tire of the wheel. The surface of the rail was now rounded, either throughout its whole upper surface or at the edges. Wrought iron, which can be obtained in a straight form for several yards together, was substituted for cast iron, whose length in a straight piece is limited. The most customary form of this description, the edge rail, has a section of the figure T, and, when curves are frequent in the road, the shape of an ⌶ was employed. In the United States, rails of wood, merely faced with iron, were adopted in consequence of the cheapness of the method.

173. After the experience of some years, it seems to be universally admitted that this combination of materials forms the best railroads. The elasticity of the wood appears to act as a spring, yielding at first to the shock of the heavy weights which are moved upon it, and then restoring itself. The road

of this combined material is therefore less injured by the traffic upon it, and the carriages which travel upon it last longer. Of all the forms of railroad, that which is composed of plates of iron laid on continuous lines of stone is the worst, in consequence of its possessing no elasticity whatever. Rails of wood are, however, liable to the important objection of want of durability. It has been proposed to obviate this by the process of Kyan, in which an insoluble compound is formed of corrosive sublimate with the albumen of the wood. From experiments which we have witnessed, it appears that this combination only takes place at the mere surface of the wood, except at the ends, and here the penetration does not exceed an eighth of an inch. It would therefore appear probable, that this method, instead of preserving, would rather hasten the decay of the heart of the wood. Under this impression, we should consider the method already spoken of, by which wood may be saturated throughout with bituminous matter, is to be preferred.

The road, having been brought to the desired grade by cutting and filling, must be allowed to consolidate itself. The foundation for receiving the rails may either be composed of cross sleepers of wood, or of blocks of stone. If the ground be not sufficiently firm, it may be rendered so by means of road-metal well rammed. The distance between the sleepers, and between the centres of the stone blocks, is usually three feet. Wooden rails may be dropped into notches cut in the sleepers; and rails, whether of wood or iron, are supported on the stone blocks, by means of clamp-shaped pieces of cast iron called chairs. The chairs are bolted down to the stone blocks, and the rails are wedged to the chairs. In *laying the rails*, room must be left for their ex-

pansion by heat; and in fastening iron on wood by spikes, the countersunk holes through which the spikes pass ought to be oblong, for the same reason.

174. Upon a level railroad of the best construction, with carriages of the most perfect finish, a horse-power is able to draw a load of about $22\frac{1}{2}$ tons. Under usual circumstances this load is about 16 tons. The resistance to motion on a level railroad has therefore been reduced as low as $\frac{1}{280}$th, and may be safely taken at $\frac{1}{200}$th. We have seen that upon the best common road it is never less than $\frac{1}{40}$th, but is, in most cases, as great as $\frac{1}{20}$th. The advantage of a good railroad over a common turnpike, when horses are employed, is therefore about 10 : 1. On the other hand, a horse draws in a boat on a canal thirty tons; and in canals which admit boats that are drawn by more than one horse, at the rate best adapted to the exertion of this kind of strength, the weight drawn increases in a higher ratio than the number of horses attached to a single boat. When, therefore, horses are the prime mover employed, a canal has an advantage in the transportation of heavy goods over a railroad, in the ratio of at least 2 : 1.

175. When speed is the object in view, as in the transportation of passengers and of valuable merchandise, the railroad has the advantage over the canal, even when horses are used as the moving power. Although some recent experiments have shown that the resistance to motion in fluids does not increase, at higher velocities, in a ratio near as great as has usually been stated, still it does not appear certain that a speed greater than ten miles an hour can be kept up upon a canal by the draught of horses. On the other hand, horses have drawn cars loaded with

passengers, on the Camden and Amboy Railroad, at an average rate of fifteen miles per hour.

176. Railroads derive their greatest value from the use of steam as the moving power. The introduction of this agent was attempted upon them at an early period in their history, but the first experiments were unsuccessful, and the engines used for the purpose are, even at the present day, receiving continual improvements. Trevithick, who was the first to apply steam to locomotion, made use of the very principle which is now successfully employed, but failed, partly in consequence of the imperfect state of railroads at the time, and partly in consequence of his not giving the principle all the extension of which it is capable. He, in fact, made use of no more than one fourth of the tractive power of which his engine was capable.

177. Two principal methods have been proposed for the propulsion of carriages upon railroads by means of steam, namely, stationary and locomotive engines. Stationary engines are set up in buildings on the sides of the roads, and their action is conveyed to the cars by means of ropes or chains. This method is attended with many inconveniences, and has therefore never been used except for surmounting considerable changes of level within a short distance; and, even in this case, the delay which attends their passage has led to the laying out of railroads in such manner as to avoid their use as far as possible.

178. In locomotive engines, after the abortive attempt of Trevithick, an apparatus resembling in structure the human leg was tried, but unsuccessfully. A more feasible plan was that of adapting a fifth *wheel, cut into teeth*, to the car, and causing it to

catch into the teeth of a rack laid parallel to the rails. This method was successfully used near Leeds, in England, for several years, in the transportation of coal, and might still be employed in cases where heavy weights are to be moved with small velocities, or raised up steep inclinations. On the other hand, the continuity of motion is not preserved, and the most important advantage to be derived from the use of steam is excluded. The method which has now superseded all others is as follows: Two or more of the wheels of a carriage being made to revolve by an engine mounted upon it, the carriage will be carried forward in consequence of the friction of these wheels upon the rails. Now, as has been shown, the least friction of the cars on a well-constructed railroad has not been found less than $\frac{1}{280}$th, and cannot be safely estimated under ordinary circumstances at less than $\frac{1}{200}$th. The locomotive engine is farther resisted by a friction growing out of the pressure of the train upon the axles of its wheels. This friction is estimated at 1 lb. per ton. To these resistances are to be added that of the air, amounting, at a velocity of twenty feet per second, to nearly 1 lb. on every square foot of the front of the leading carriage.

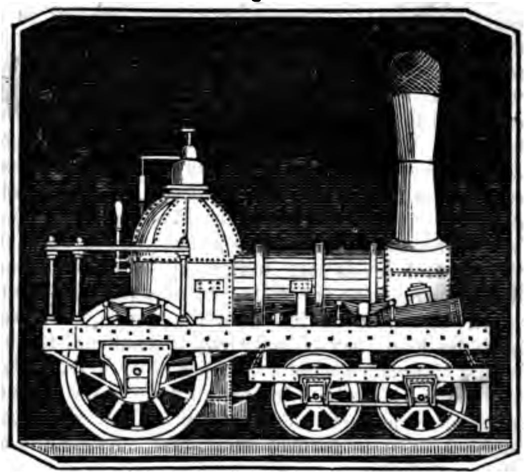
To overcome these, we have the friction of iron upon iron at the points where the wheels touch the rail. This friction is about $\frac{2}{7}$ths of the pressure. But, as dust or other moveable substances may intervene, as the rail may be moistened with rain or dew, or even coated with ice, the efficient adhesion cannot be safely taken at much more than $\frac{1}{6}$th. Admitting this fraction for the measure of the adhesion, and $\frac{1}{200}$th for the measure of the resistances, a locomotive ought to be able to drag after it any weight less than 32 times that which rests on the wheels which are driv-

en by the engine; and there are instances in which an engine has drawn 50 times its own weight. In practice, however, the load is usually limited to 25 times the pressure which the locomotive exerts on the rails, when moving with a velocity of 12½ miles per hour, and with steam of the expansive force of 50 lbs. per inch.

179. It is easy, by means of a crank, to cause two of the wheels of a locomotive engine to revolve, and two others may be readily made to move with them by connecting rods. It is, however, so difficult to give exactly the same diameter to all the wheels, that it has been often found, that of the two wheels united by a connecting rod, one alone was efficient, and hence it is usual to restrict the number of wheels driven by the engine to two. On this account, curricle engines, in which the whole weight is carried on no more than two wheels, were at one time tried, but were not approved of. The most efficient locomotive engines which are at present in use, rest upon six wheels. Two of these are much larger than the others, and are driven by the engine. In England, these wheels are placed between the others. In this country the four small wheels are combined in a single frame under one end of the carriage, and the other end rests on the two large wheels. The first engine of the latter description was planned for the use of the Mohawk and Hudson Railroad, by Mr. J. B. Jervis, at that time chief engineer of that work, as long since as 1826.

180. A locomotive engine is in all cases propelled by steam of high pressure. The reasons which forbid the use of the condensing engine have been stated in § 119. The cylinder of the engine may be either *horizontal* or vertical, and in many cases has

Fig. 55.



been placed in an inclined position. Two cylinders are generally employed. These not only serve to adjust the weight more conveniently, but they may be geared to cranks placed upon the same axle, at right angles to each other, and thus one will be at the middle of its stroke, and therefore acting with its greatest intensity, at the time that the other is passing the centre. The motion will be rendered in this way more equable. To the piston-rod of each cylinder a connecting rod is adapted, which is applied at its other extremity to a crank on the axle of one of the pairs of wheels on which the engine is carried. This pair of wheels is thus caused to revolve.

An engine of the latest construction, with six wheels, the two larger of which are driven by a cylinder on each side of the boiler, is represented Fig. 55.

181. As the resistance upon a railroad, under the most favourable circumstances, is $\frac{1}{280}$th, and as it does not amount on any well-constructed railroad to more than $\frac{1}{200}$th, it follows that the greatest slope which can be admitted upon a road, without an increase in the moving power, or a diminution in the load, is 1 foot in 200, or 26 feet per mile. Railroads, therefore, wherever economy in the cost of transportation is the principal object, are to be laid out in a series of levels or slopes not exceeding $\frac{1}{200}$. When this mode of laying out the road is adopted, the several levels are united by inclined planes. When passengers are conveyed on such roads with great velocities, the power of the engine, compared with its load, may be sufficient to enable it to surmount the planes with a diminished velocity. This method is applicable with certainty up to the limit of $\frac{1}{80}$th, or 64 feet per mile, and some of our American engines have performed their task successfully on slopes of $\frac{1}{14}$th.

At greater inclinations, or when heavy loads are carried at small velocities, additional power may be required to ascend the planes. This may be furnished, either by a stationary, or by an additional locomotive engine. Whenever the inclination of the plane exceeds $\frac{1}{25}$th, it would be better to resort to stationary engines ; but as their use is a great cause of delay, engineers usually endeavour to give a less slope to their inclined planes, and thus render them capable of being surmounted by a locomotive engine.

Even a slope of 26 feet per mile cannot be overcome without a diminution in the velocity, and this will begin to be distinctly obvious whenever the slope exceeds $\frac{1}{400}$, or 13 feet per mile.

The locomotives used for this purpose are heavy

and all their wheels are caused to turn by the engine, in order that all their several adhesions may concur in the effect. Engines constructed for this purpose are called bank engines, and one is stationed at each inclined plane.

182. When the greater part of the trade on a railroad is in the descending direction, the loaded cars may be made to draw up such as are empty. In the latter case, it is necessary to apply means for preventing the acceleration of the descending cars. The best method yet employed for this purpose is that introduced by Mr. J. B. Jervis, on the railroad of the Hudson and Delaware Canal Co. It is composed of a wheel revolving on a vertical axis, and furnished with leaves, whose motion through the air is resisted. It is, in fact, the method of a fly with leaves, referred to in § 16. Friction may also be applied by a brake to the wheels of each car; but this method requires several men for its application, while the former is self-acting.

183. Railroads ought not only to be nearly level, but also as straight as possible. Curved railroads are objectionable for several reasons:

(1.) The axles have so little play, that, in turning in curves, one of the wheels on each axle must drag or pass along the rail by sliding, as well as by its revolution. The resistance is in this case materially increased.

(2.) In changing the direction of the course of cars, there is a great risk incurred of their running off the rails.

(3.) A centrifugal force is produced at the curves, by which a pressure takes place on the outer rail, causing an increase in the lateral friction, and a tendency to spread the rails or separate them from each other.

In changing the direction of the lines of railroads, the curves must, in consequence, be made of the largest possible radius; and to lessen the action of the two last of the above causes, the outer rail should be raised above the level of the other. The amount of this elevation will depend on the breadth of the track, the radius of the curve, and the velocity of the car.* If the velocity be thirty miles per hour, the elevation of the outer rail, in a track of mean width, should be nearly thirteen inches when the radius of the curve is 250 feet; with the same velocity, the elevation becomes 6½ inches at 500 feet radius; 3⅓d inches at 1000 feet; 1⅔ds at 2000 feet.

It is also usual to make the tire of the wheels slightly conical when curves frequently occur on a railroad; this gives facility in changing the direction of the carriage, and moderates the centrifugal force. This method, however, is not without objection upon the straight parts of the road. A method, which is considered better, consists in uniting the flanch with the rest of the tire by a conical surface. This has all the advantage of a conical wheel at the curves, and is not liable to objection on the straight parts of the road.

184. Tram-roads being intended for the use of common carriages, the distance between the rails was made the same as that of an ordinary wheel track, say four feet eight inches. Although no such reason applies to railroads in their present state, it has still been usual to limit the space between the rails to this distance. It would, however, appear that there is no good reason for this practice, and there are obvious advantages to be derived from an increase in the width of the track. The height of the wheels

* See Pambour on Railroads.

must bear such a relation to this width as will prevent the equilibrium of the cars from becoming unstable, and this gives a limit to the radius of the wheel, considered as a lever, which prevents its being as effectual in overcoming the friction as it ought to be. An increase in the diameter of the driving-wheels of locomotives will also be favourable to velocity with a given force of steam. For these reasons, on a railroad recently made in Russia, the breadth of the track has been made six feet; and in the Western Railroad, in England, the breadth has been made as great as eight feet. The latter, however, appears to be excessive.

185. It might at first appear that, as the weight which can be drawn bears an exact ratio to the weight of the locomotive, the heavier the latter is made the better. The attendance upon a large and small engine is the same, and thus the expense of the larger engine is less in proportion. Engineers were for a time misled with this view of the subject.

It is to be considered that every increase in the weight of the engine is attended with increased wear and tear in the roads and in the engine itself, and it has, in consequence, been inferred that it is better to diminish the weight of the locomotive to the lowest limit consistent with strength and the efficient generation of the steam required for working it.

Two conditions are to be observed in planning an engine to draw a given load:

(1.) That there shall be such proportion between the boiler and the cylinder as shall furnish steam of the necessary pressure at the required velocity.

(2.) That the weight of the engine be sufficient to give the adhesion which is in dynamical equilibrio with this pressure.

If the power of the steam exceed the state of equi-

librium with the pressure, all such excess will be lost; and if the pressure be in excess, all such pressure is a useless load.

In locomotive engines intended for rapid motion, it has been found most advantageous to make use of the pressure on no more than one pair of wheels. On the other hand, when the power of ascending planes is required, not only are heavy engines best, but all the wheels must be so connected as to derive motion from the engine.

It has not been found expedient to reduce the weight of a locomotive below eight or nine tons, including the water in the boiler and all necessary accessories. The fuel and water of supply are carried on a separate car, denominated the *Tender*.

With an engine of the weight of 8 tons, the maximum load has been as much as 175 tons, with the velocity of 12½ miles per hour.

In doubling the velocity, the load is diminished to one eighth, while the expenditure of fuel in a given distance is only lessened one half.

As an instance of good performance of a locomotive engine, we may cite that of one constructed by Messrs. H. R. Dunham & Co., of New-York, on the Harlem Railroad. The whole weight of this engine was 20,400 lbs., or, as nearly as possible, 9 tons, when the boiler was filled with water and the engine in working order. Of this weight 10,680 lbs. bore on the driving-wheels. The load drawn was 105 tons, loaded upon 35 cars, whose weight is not given. The ascent overcome on parts of the road was between 25 and 30 feet per mile.

VIII.

CANALS AND DOCKS.

186. CANALS are artificial channels for the conveyance of water, and their most important use is for purposes of navigation. They may be applied to this object in three different cases, namely: 1. To form a communication between two navigations upon the same level, or one of which is higher than the other, drawing their supply of water from one or both of these navigable waters; 2. As a substitute for a stream which is not itself navigable, in consequence of obstructions or of too great rapidity; or, 3. To form a communication between navigations, both of which are lower than the ground over which the canal must necessarily pass. The latter case is the most important in practice, and a canal of this description is said to have a summit level, or to be *à point de partage*. The possibility of passing canals over ground more elevated than the navigations they were intended to unite was first pointed out by Riquet, and put into practice in the Canal of Languedoc.

187. When a canal is of this description, it is necessary that the water for its supply should be collected in reservoirs, or carried by feeders to the point whence it is to flow in opposite directions. These feeders must be cut along the slopes of the higher grounds, in such manner as to intercept all the streams and surface-water that flow over them.*

* The mode of calculating the slopes and areas necessary for conveying the required quantity of water may be seen in the author's Treatise on Mechanics, book vi., chap. vi.

188. The quantity of water which may be intercepted by a feeder is ascertained by gauging the streams, or estimating the quantity of rain which falls upon the surface whose slope is directed to the same feeder.*

189. The dimensions of a canal may be determined from certain considerations of circumstances under which they are placed. When they are intended to join two artificial navigations, their dimensions must not exceed the smaller of the two, otherwise transhipment may be necessary at the point of junction. When they unite two natural navigations, they should be constructed to accommodate the smallest class of vessels which can safely navigate them, unless the amount of trade be insufficient to warrant the expense. Thus the Raritan and Delaware Canal has, with great propriety, been adapted to the passage of river-craft of 80 tons. But, when no such considerations need be taken into account, the best size for canals is that suited for vessels which may be drawn by a single horse. These carry 35 tons, and may be conveniently made of the following dimensions: length 60 feet, beam 8 feet, draught of water 3 feet.

190. The area of a canal must be such as will permit two boats to pass each other, although a third may be lying near the side. The depth must be one foot greater than the draught of the vessels, in order that they may run no risk of touching the ground. The bottom is level, and the sides have such a slope as the earth of which they are composed naturally assumes. The breadth at bottom is therefore usually twice as great as the beam of the vessels. The

* The method of gauging streams will be found in the author's *Treatise on Mechanics*, book vi., chap vi.

canal is included between two banks, which may, according to circumstances, be cut in the ground, or formed by embankment. One of these is used as a towing-path for the horses which draw the boat: its breadth at top must not be less than six feet, and it ought to be covered with good materials for roads. The other bank need have no greater thickness than is necessary to resist the action of the water in the canal. When the natural earth is retentive of water, the banks are formed of it alone. When it is not, the canal is either lined with an earth retentive of water, or a vertical layer of such earth is worked up in the middle of the bank. This mode of lining is called puddling. The best puddling material is a gravelly loam. Clay will not answer the purpose, as it will not resist the action of moving water. The banks of the Erie Canal have in many places been lined with a pavement of rolled pebbles.

A level surface or berm ought to be left between the surface of the water in the canal and the two banks, in order to prevent the earth from falling from them into the canal. A ditch should be cut on each side of the canal in level ground, and on its upper side in side-lying grounds, in order to prevent surface-water from running into the canal. The surface-water which accumulates in the ditches must be passed under the canal from time to time, in passages acting like inverted siphons. These are called culverts.

191. A canal, whatever be the height of its summit level, is laid out in a series of levels. These levels may be made to communicate with each other by means of locks or of inclined planes. The former are used when the differences of level are not great, and the practicability of a canal is usually judged of in reference to this method; but the incli-

ned plane has at last been successfully used in the Morris Canal, and the possibility of passing canals through mountainous regions is thus established by actual experiment.

A lock is a chamber usually formed of two walls of masonry, and closed at each end by gates. The top of both gates rises as high as the surface of the water in the higher level of the canal. The lower gate has its sill on a level with the bottom or lower reach of the canal, and the sill of the upper gate is usually established upon a wall rising like a step to the bottom of the upper reach. This breast-wall is the weakest part of the lock, and in modern American locks it has been suppressed. The change of level in the bottom of the canal is then made gradually above the site of the upper gate. For this improvement the world is indebted to the late Canvass White, and it is the only important step in lock navigation made since the construction of the Canal of Languedoc.

The gates of canals are usually made in two leaves, meeting at an angle in the middle of the lock. This angle is pointed towards the upper level, and its most advantageous dimension is 120°.

Paddle-gates are formed in these gates for the passage of water from the upper level into the lock, and from the lock into the lower level of the canal. Culverts, furnished with gates for the same purpose, are also sometimes made in the walls of the lock. These were absolutely necessary for the upper gate before the improvement of White, as the water, running through an opening in the upper gate, might have spouted into a boat occupying the lock. Such culverts weaken a lock, and therefore should, if possible, be dispensed with.

When the lower gate is shut, and water passed

through the paddle-gate from the upper level, the lock may be filled with water. The pressure on the opposite sides of the upper gate will then become equal, and it may be opened, while the lower gate is kept tightly shut by the pressure of the water in the lock. By shutting the upper gate, and allowing water to escape through the paddle-gate into the lower level, the lock may be emptied, and the lower gate being under equal pressures, may be opened. Vessels may therefore be drawn in the two cases from the two levels, and alternately raised and lowered, within the lock, from the one to the other.

The alternate filling and emptying of a lock takes about ten minutes, and thus, in a canal fitted for 30 ton boats, 360,000 tons may be passed through the locks in each direction in the course of a year. This exceeds the traffic on the most frequented canal, and therefore, even if of this small size, it will be sufficient for any practical purpose. On the other hand, a greater weight will be drawn upon large canals by a given number of horses than upon small canals, for the resistance to boats of similar figures increases only with the squares of their lineal dimensions, while their burden increases with the cubes.

The course of trade in the Northern States diminishes the capacity of the canals for transportation very materially. In the autumn, towards the close of the navigation, the agricultural products of the interior are accumulated in great quantities, and crowd the canals, while, at the same time, foreign manufactures and objects of consumption are hurried from the seaports, in order to supply the winter's demand. Early in the spring, the merchandise which has accumulated during the winter also seeks its market, at the earliest possible period. For this reason, in the autumn just before the navigation closes, and

in the spring immediately after it opens, our canals are insufficient for the transportation of the vessels. At other seasons the locks are almost idle. It thus happens, that although as many tons have passed locks on a 30 ton canal in England as pass those on the Erie Canal, where the vessels have a burden of 60 tons, there is much more complaint of delay on the latter than on the former. This complaint has led to a resolution, on the part of the State of New-York, to enlarge that canal, and place two locks side by side, at each change of level. It is foreign to our purpose to inquire how far such an additional expense is warranted by the circumstances of the case, or likely to return an adequate income. It is, however, certain that the cost of transportation will be lowered, and room will therefore be left for an increase in the tolls.

192. The difference of level which may be overcome by a single lock will depend upon the cost of construction, and the quantity of water required to fill it. The latter increases with every increase of the height of the lock; the former is a minimum between the heights of eight and ten feet. All the locks on either side of the summit level of a canal are usually made of the same height, in order that the water discharged from one shall exactly fill that below it, and thus there may be no waste, or no need of an additional supply of water. A better rule is to make the locks diminish in height from the place where a feeder enters, in order that the other causes of waste of water may be compensated.

When the difference of level between two parts of a canal is greater than can be overcome by a single lock, the locks must not be placed in juxtaposition, otherwise a single boat will occupy the system for the length of time necessary to pass all the several locks,

and the expenditure of water will be proportioned to their number. Nor must the intervening space be limited to that necessary for two boats to pass, otherwise the quantity of water drawn to fill a lock might leave the boats aground. When circumstances compel the engineer to place locks in juxtaposition, the system ought to be double, so that one set may be occupied by the ascending, the other by the descending vessels.

193. In the inclined plane proposed by Fulton, the boats, being placed on carriages while in the water, were drawn over a ridge having a slope in both directions, by a force derived from a vessel of water descending in a vertical well. A similar double plane was used by Kitchell on the Morris Canal, but the power was derived from a water-wheel. In the inclined plane of the Duke of Bridgewater's mines, the boats passed from the upper level into locks, on the emptying of which they rested on the carriages; the trade being a descending one, the loaded boats draw up the empty ones. In the inclined planes now in use on the Morris Canal, the method of locks at the head of the plane is imitated; but as the trade is alternating, the power is derived from a water-wheel.

Water-wheels are objectionable as a power for the inclined planes of a canal, because they require a continual supply of water, which, at heights of more than 40 feet, may exceed that necessary to fill a lock. A water counterpoise moving on a parallel inclined plane, where the quantity of water necessary to set the system in motion would continue the motion through any change of level whatever, is therefore preferable. This is the method which was proposed by the author in the original project of the Morris Canal.

194. The supply of water for a canal dep

upon the quantity required for lockage, the evaporation from the surface, the leakage through the banks and through the joints of the gates. In respect to lockage, a lock full of water is allowed for every boat which will probably pass, although one is sufficient for letting one boat up and another down. The excess of evaporation over rain is usually taken at a depth of three feet on the surface of the canal in a year. The leakage through the banks is estimated at double this amount. It is sufficient to allow for the leakage of one gate on each side of the summit level, as the water which thus escapes from one gate is caught, and supplies the leakage of that beneath it.

In practice in the United States, the mode of estimating the necessary supply of water which has just been stated, is said to be far from sufficient. The engineers who are employed on the Erie Canal have stated officially, that the demand of water for its service amounts to 100 cubic feet per mile every minute. The same estimate has been reached in the canals of the State of Pennsylvania. In conformity with the former estimate, it has been inferred that the Erie Canal, when enlarged, will require a supply every minute of 200 cubic feet per mile. In order to convey forward such large bodies of water from distant sources, it becomes necessary to give a slope to the bed of the canal between the two locks which close each of its levels or ponds; and the larger the pond, the greater the slope which must be given to its bed. A farther increase in the flow will be gained by making the canal diminish, both in breadth at the surface and depth, as the distance from the source of supply diminishes. For want of such precautions in the outset, much difficulty has been found in some places in furnishing the necessary supply of water. *This is particularly* the case in the level which ex-

tends for about 60 miles from Lockport to Rochester, along which it was originally intended to convey water from Lake Erie to supply the canal for a distance of 80 miles farther to the eastward.

195. The other structures which are necessary on canals, are: waste gates, by which any excess of water may be discharged; waste weirs, by which it may be prevented from rising above a proper level; these are prismatic mounds of masonry, whose edge is on the level at which the water ought to be maintained; culverts, by which streams, whose level is nearly the same with that of the canal, may be passed beneath it; and aqueducts, having the form of bridges, by which the canal may be carried over deep valleys and wide water-courses.

Aqueducts may be trunks of wood resting on piers of masonry. These have the advantage, in this country, of saving in the original cost, but are objected to for want of durability. It would, however, appear, from the experience of the Erie Canal, that they have lasted as long as some of those built of stone.

The best aqueducts are formed of plates of cast iron, united by bolts passed through flanches. These may be supported on pillars of stone, when they can be placed near enough to dispense with the use of the arch. In other cases they are supported on arches of cast iron. The finest aqueduct of this description is in the Valley of Llangollen, in Wales, on the Ellesmere Canal.

196. Wet Docks are basins constructed in places where there is a considerable fall of the tide, in order to keep vessels afloat when the tide ebbs. They are connected with the tide-way by gates resembling those of a canal lock, and these gates are sometimes two in number, having a space between them

sufficient to contain a vessel. This space may therefore be made to answer the purpose of a lock. The best specimens of these basins are those in the vicinity of London, a description of which may be found in "The Public Works of Great Britain," and those of Liverpool.

197. A Dry Dock is a basin into which a vessel may be floated, and shut up by gates. The water is then discharged either by the fall of the tide, or pumped out when that is not sufficient. A vessel may thus be laid dry for the purpose of repair. The gates are usually similar to those of a canal lock or wet dock, but open in the opposite direction, or outward. Besides this kind of gate, a floating gate is often used in dry docks. This is a vessel of such length and depth as to occupy the whole opening of the dock. The walls have two deep grooves cut opposite to each other in the masonry, and united by a horizontal groove at bottom. The walls are inclined towards each other, so that the vessel may lie lengthwise between them when afloat, but will enter the grooves while in the act of sinking, and fill them when it reaches the bottom. The floating gate, being introduced in this place, is caused to sink by admitting water through an opening in its bottom. When the gate is to be removed, this opening is closed, and the water pumped out.

Dry docks are of absolute necessity for the repair of large vessels, and a navy cannot be maintained in an efficient state without them.

For smaller vessels, the Marine Railway of Morton, the Screw Dock, the Hydraulic Dock, and a Floating Dock recently introduced in New-York, may suffice, and are less costly than the Dry Dock.

In Great Britain, where the tide falls enough to permit the docks to be emptied by its ebb alone, and

where the space on which the dock is to be constructed is dry at low water, no great difficulty exists in the construction of a dry dock. In most parts of the United States, this facility is not to be found. They have therefore been built at Norfolk and Charlestown, Mass., by means of a coffer-dam, enclosing the space they were intended to occupy. This method appears to be much less efficient, and far more costly than that used under similar circumstances at Toulon, where the dock was built in a large floating vessel or *caisson*, and was sunk by its own weight upon a foundation of piles.

198. Canals are also used for the purpose of conveying water for the supply of cities, in which case they are called aqueducts. It generally happens that, where ground is covered with buildings and the streets paved, the springs subside, and finally disappear. Even when the springs derive their water from distant sources, it is apt to be contaminated by the filth which the surface-water carries through such parts of the ground as can be penetrated by it. In other cases, the usual supply being cut off from above, water charged with foreign matter may pass in, even if it do not rise to as great a height. These facts have all been illustrated in the city of New-York. The level of the springs has fallen, and in some cases wells, once abundantly supplied, have been dried up. The water is so highly charged with organic matter in the wells of the older parts of the city, as to become putrid after a few hours; and springs which formerly yielded a pure and soft water have become brackish.

199. The best source for the supply of a city is a stream which has run for some distance in a steady and gentle current. Under such circumstances, it

is found that all saline matter is precipitated, and organic matter ceases to be soluble. No other impurity remains but what is visible in the form of sediment, and this is readily removed by allowing the water to remain at rest for a time, or by actual filtration. Such is the effect of exposure to the sun and air upon water, however charged with foreign matter, that the superior excellence of the waters of such rivers as the Nile and the Mississippi is acknowledged by all who have tasted them. On the other hand, when water is actually stagnant, it will likewise deposite its earthy salts; but the smallest quantity of organic matter will, in a hot climate, render it unwholesome not only to those who drink it, but to those who reside in the neighbourhood.

200. In conformity with these facts, the best mode of conveying water for the supply of a city would be in a channel open to the air. It ought, moreover, to be of such a depth that the bed may be below the reach of frost, and with such velocity as will prevent more than a thin crust of ice to form at its surface. Channels of masonry, however well built, are not only expensive, but are objectionable in consequence of the water being capable of dissolving a portion of the lime which is contained in the mortar, unless the joints be both close and few in number. The best of all beds for the purpose is one of retentive earth, such as would be suited for puddling the banks of a navigable canal, but containing a larger proportion of gravel, in order to resist the greater velocity of the water. One of the best instances of this description is the New River, by which a great part of the city of London is supplied. This brings the water from a distance of 39 miles, and, by the joint *advantages* of favourable ground and good engineering, *is one* uninterrupted line of canal upon a constant slope.

201. After water has been conveyed for some distance in an open channel, it is necessary that it should be permitted to rest for a time, in order to regain the air which separates from it while in motion, and deposite the sediment. Reservoirs are also necessary to equalize the supply, husbanding the water when it is not demanded, in order to yield it when wanted. One of the best reservoirs is that of Toulouse, in France. It is a large basin, excavated to a considerable depth. In the bottom is placed a layer of large rolled stones, at as great a distance from each other as will permit of their supporting a second layer of less size. Successive layers, thus decreasing in size, are placed in the reservoir, until the upper beds take the form of coarse gravel, and these are covered with sand. The interstices in this material are sufficient to hold the required supply, and it is under the circumstances of water in a well, having a temperature nearly constant throughout the year.

This reservoir is not supplied by a canal, but is excavated in a gravelly soil, so near to the bed of the river Garonne that its waters filter through the narrow dike of loose soil which separates them, and thus reach the reservoir clear and limpid.

A similar plan is adopted at Glasgow, in Scotland. A deep trench was cut in a gravelly point almost surrounded by the Clyde. In this a tunnel of an elliptic shape was laid of brick, backed and jointed only with sand. The trench was then filled up. The water of the river filters through the gravel and fills the tunnel, whence it is drawn for use.

202. When a body of good water exists in the neighbourhood of a city at a low level, or when it is brought from a distance at an elevation too small to permit it to be used, it becomes necessary to raise

by artificial means. One of the earliest instances of this sort was in the supply of a part of London. The water of the Thames is fresh at London Bridge, and in the old structure of that name, the current through the arches is sufficiently strong to work an undershot water-wheel, both during the rise and fall of the tide. On the axle of this wheel were placed three cranks, each of which worked the rod of a pump, by which the water was forced to the top of a lofty tower.

At Philadelphia, the water of the Schuylkill is formed into a pond by a dam. This furnishes a power to drive breast-wheels, by which a set of horizontal forcing-pumps is worked.

203. As water-power can only be obtained in particular situations, the steam-engine furnishes a method more universally applicable for raising water. This is made use of by the Manhattan Co. of New-York, and was formerly employed in Philadelphia. In London, the pulling down of London Bridge has destroyed the water-power of which we have spoken, and it is replaced by a steam-engine. Other engines are erected at different points on that river, by which, in addition to the New River, the prodigal supply with which that city is furnished is obtained.

204. When a channel by which water is conveyed to a city reaches a deep valley or stream which crosses the direction of its course, two methods suggest themselves for crossing it. The first and most ancient is by an aqueduct bridge of masonry; the second by means of pipes forming an inverted siphon, in which water will rise again nearly to the height at which it enters. The first method was practised by the Romans, and did not go out of use until after the age of *Louis* XIV. The last instance of a stone

aqueduct is even later, for one was constructed near Lisbon towards the close of the last century, under the orders of Pombal.

The second method was not practicable until the art of casting iron had attained a certain degreee of perfection, and this art had not yet penetrated into Portugal.

Our contemporaries, who are aware of the advantages of conveying water across valleys by means of pipes, have supposed that the profuse use of aqueduct bridges of masonry by the Romans grew out of their ignorance of the property of water, by which it tends to rise to the level of its source or head. The reason for the use of such aqueducts was different. The Romans were unacquainted with cast iron, and were therefore compelled to make such water-pipes as they could not avoid the use of, of lead. This metal is so rare and costly, that the stone aqueducts had the advantage of economy. At present this reason does not apply, and it is vastly cheaper to convey water over a valley in pipes than in an aqueduct of masonry. Even where it is necessary to construct arches, a saving of expense may be obtained by making the surface of the bridge incline downward each way to the middle of the valley, and laying the pipes upon it. Such is the beautiful aqueduct of Genoa, and such was the plan of the method of crossing the Harlem River proposed by the engineers of the Croton Aqueduct. It is to be regretted that this plan, which would have been so highly creditable to the intelligence of our people and the science of our engineers, should have been abandoned, under the compulsion of an act of the Legislature, for one resembling the exploded structures of the engineers of ancient Rome and of the dark ages.

Besides the objections in point of cost, lofty aque-

ducts of masonry are liable to the farther defect of exposing the water which flows in them to freeze. This has led to the abandonment of a masonry aqueduct raised upon arches, in a climate even less severe than our own. It is many centuries since the continual interruption caused by the frost has led to the substitution of leaden pipes for the aqueduct erected by the Roman emperors at Constantinople.

205. Water is wanted in cities for two purposes: the supply of the inhabitants for cooking, washing, and drinking, and the cleansing of the streets and sewers. The former ought to be raised to the highest stories of houses, while the latter need be delivered at no higher level than the surface of the streets. But a small quantity of water is wanted for the former purpose compared with that for the latter. In London, the delivery at two different levels is managed in an easy and economic way. For the greater part of the 24 hours, the water is distributed from a reservoir whose level is little higher than the most elevated point of the streets, and the engine raises a large body to that height. But, for a few hours in each day, the engine pumps a less quantity of water into a small reservoir situated as high as the top of the loftiest houses. By a simple stopcock, the pipes by which the water is conveyed may be put in communication with either of the reservoirs. While in communication with the larger, the water will only run at or below the level of the streets; and when in communication with the latter, it may be drawn in the uppermost stories of dwellings. Here cisterns are placed, by which a supply is furnished at times when the system is in communication with the higher reservoir.

206. Water is conveyed from the reservoirs and

distributed throughout the quarters of a city in pipes of cast iron. The proper dimensions of such pipes may be made a matter of almost strict mathematical calculation.*

207. When water is running in pipes it is liable to obstructions. These are of two kinds:

(1.) Water flowing in a pipe gives out its air. This collects in the higher joints of the pipe, and forms an obstruction as effectual as if it were a solid body.

(2.) If the water be not perfectly clear, it will deposite its sediment in the lower joints of the pipe, and may finally close it at these places altogether.

The first of these obstructions may be prevented by placing a valve opening downward at the highest bends of the pipe. This is connected by a rod with a hollow ball, which, being lighter than water, keeps the valve shut so long as the pipe is full of that liquid. But when air collects, the ball falls and opens the valve. The air escapes, but is followed by the water, which raises the ball by its buoyant force, and shuts the valve.

Deposites of sediment may be removed, wherever the ground falls from the lowest bend of the pipe, by means of a stopcock. This is opened from time to time, and the water, flowing rapidly out, carries the earthy matter along with it. In other cases a short pipe is placed beneath the lower angles of the water-pipe, and communicates with it in two places by leaden tubes. The sediment, seeking the lowest level, will be formed in this pipe, which may be removed from time to time and emptied.

* See Genieys' Moyens d'élever et de conduire les eaux, and Storrow on Water-works. Perhaps the best practical rules are to be found in Brewster's Cyclopædia, article "Hydraulics."

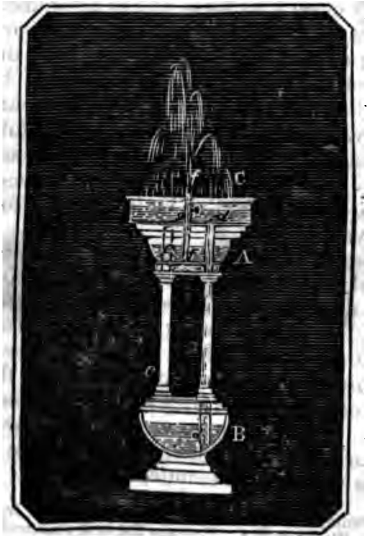
IX.

HYDRAULIC ENGINES.

1. *Fountain of Hero.*

208. The Fountain of Hero consists of two vessels, A and B, the one placed perpendicularly over

Fig. 56.



the other, and both air-tight. Upon the upper vessel is an open cistern, C. A pipe, d d, proceeds from

the cistern, passing through the upper vessel without communicating with it, and entering the lower vessel, reaches nearly to its bottom. A second pipe, *e e*, proceeds from the top of the lower vessel, and entering the upper, rises nearly to its top. A third pipe, *f f*, is inserted into the top of the upper vessel, and reaches within a small distance of its bottom; this last pipe is terminated by a nozzle or adjutage. The last pipe is furnished with a stopcock at *g*; and there are stopcocks for the admission and discharge of air and water.

In order to set the machine in action, the upper vessel is filled with water nearly to the level of the open end of the pipe *e e*, and water is introduced into the lower vessel until the open end of the pipe *d d*, is immersed. The stopcocks which have been opened for this purpose, are now closed, and water is poured into the cistern C. This enters and fills the pipe *d d*, forming a column of the whole height of the instrument; by this the air contained in the upper part of the two vessels, and in the pipe *e e*, is compressed, and thus, having its elasticity increased, acts upon the surface of the water in the vessel A with a force whose measure is the fluid pressure of the column in *d d*. The stopcock *g* is now opened, and a jet of water is forced by this pressure out of the adjutage in which the pipe *f f* terminates. The action will continue until the water is forced out of A to the level of the lower end of the pipe *f f*, and the lower vessel B is nearly filled with water; and it may be repeated by allowing the air to escape from the vessel A, and the excess of water to run out of the vessel B.

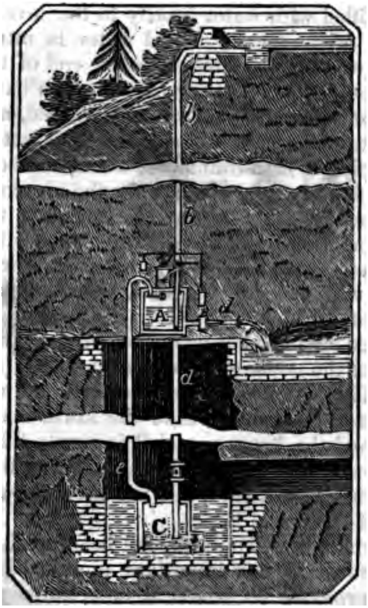
The Fountain of Hero has not been applied, in its original form, to any important practical purpose. But the principle on which it acts, namely, that of

compressing a body of air by a column of fluid, the air acting in its turn to raise a second column of fluid, has been advantageously employed in the instance we shall next cite.

2. *Machine of Schemnitz.*

209. The mine of Schemnitz, in Hungary, is situated in a mountain which rises suddenly from a plain. The mine was at first drained by means of a horizontal gallery driven in from the surface of the plain. When the vein had been exhausted down to this

Fig. 57.



level, a spring of water, situated on the side of the mountain, was made use of to drain it, in the following manner:

A large airtight vessel, A, was placed in the horizontal gallery. Into this the water of the spring was conveyed by the pipe *b b b*. The air in A being compressed by the column of water in this pipe, acted through the pipe *e e*, upon the surface of the water received from the bottom of the mine in the vessel C, and caused it to rise in the pipe *d d*, and flow out at the level of the horizontal gallery. The height of the spring above this gallery was 158 feet, the depth of the mine 103 feet. With this difference of altitude, the quantity of water raised from the mine was $\frac{41}{100}$ of that derived from the spring.

The upper vessel having been filled with water, and all that in the lower having been forced out, the action of the machine is renewed by opening four stopcocks, by which the upper vessel is again filled with air and the lower with water.

3. *Pump of Vialon.*

210. The pump of Vialon is composed of two pipes, wound in opposite directions around the same cylinder, at the top of which they are united in a single tube in the direction of its axis. Each tube terminates in a funnel-shaped opening in the direction of a tangent to the circular base of the cylinder, and a valve opening upward is placed immediately above each funnel. The motion given to the instrument is reciprocating, and at each alternation water enters by one of the funnels, while it is retained in the other by the closing of the valve. The two streams will finally meet in a vertical pipe.

This instrument is represented in Fig. 58, on page 192.

Fig. 58.

4. *Bucket Machine.*

211. Two buckets, connected by chains or ropes passing over a pulley, may constitute an engine for raising water. The buckets are of different sizes, and the smaller is loaded with such a weight as to be heavier than the larger when empty, but the capacity of the larger is so great that it shall preponderate when both are filled with water. Both buckets receive water from the same stream and at the same level. The pulley must be placed sufficiently high to allow the smaller bucket to ascend to the height at which the raised water is to be discharged, and a *well must be formed* to permit the descent of the lar-

ger bucket to an equal depth below the level at which both receive water. When they have respectively reached the highest and lowest points of their motion, the water is made to discharge itself from both at the same instant; and the smaller bucket becoming heavier, descends and draws up the larger bucket until both resume their original position, when they are again filled with water, and motion is caused in the opposite direction.

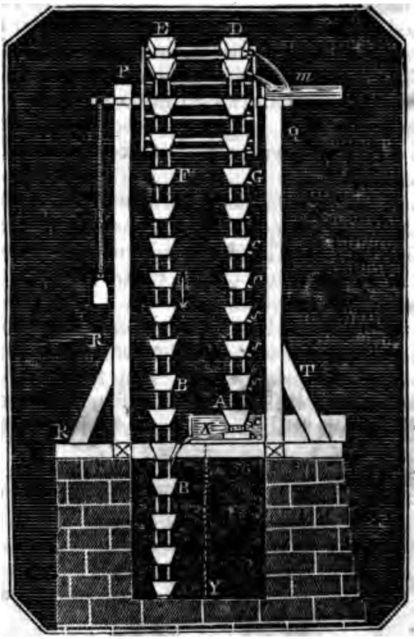
The discharge of the water from the buckets may be effected in various ways. The most ingenious in principle consists in taking advantage of the difference in the position of the centre of gravity* of a hollow and a solid conic frustum. The buckets are suspended on an axis lying between these two points, and hence are in stable equilibrium when empty, but in one of tottering equilibrium when full. The smallest shock will therefore suffice to upset them when full, but, after the water is discharged, they return to their primitive position.

212. Two chains of buckets, passing over the same axle, but having their openings in different directions, may be made to answer a similar purpose. The motion of this is continuous. The arrangement will be understood by inspection of the annexed plate. (See Fig. 59, on page 194.)

Where it may be inconvenient to dig a well of sufficient depth to allow the larger bucket to descend as far as the smaller bucket rises, two pullies may be used of different diameters; and the larger bucket, being attached to the smaller of these, will descend through a space as much less than that through which the smaller bucket rises as the diameter of the one pulley is less than that of the other.

* See Mechanics, § 105.

Fig. 59.



R R P Q T is a wooden frame, through the top of which is passed the axle of the lantern D E F G.

B B F E is a chain of buckets, which receives water at X from a reservoir. This chain of buckets descends into a well which is deep enough to enable the buckets, when full of water, to set in motion those loaded with the water which is to be raised.

A G D is a chain of buckets, the lower one of which is immersed, as it revolves, in the reservoir X. Each bucket has a spout near its top, through which the water flows out, as represented at *m*, as soon as the bucket begins to be inclined by reaching the curved surface of the lantern.

5. *Siphon of Venturi.*

213. When water is flowing from a reservoir through a cylindric tube of no great length, it does not fill the tube, but forms what is called the *Vena Contracta.** The air contained in the space between the contracted column of water and the sides of the tube will be drawn out by the motion of the liquid. This action is analogous to friction, and is called the lateral communication of motion in fluids. If, now, a bent pipe of smaller size be inserted into the tube through which the water is discharged, and pass down into the reservoir of water beneath, the air which this pipe contains will also be carried along with the current of water above; and the pressure of the atmosphere, acting upon the surface of the water in the pipe thus rendered void of air, will force it up, and cause it to join the effluent stream. The quantity thus raised will be small, but there are cases in which it might be used to great advantage. The limit of the height to which water can be raised by this engine is the same as in the common pump, say in no case more than 34 feet.

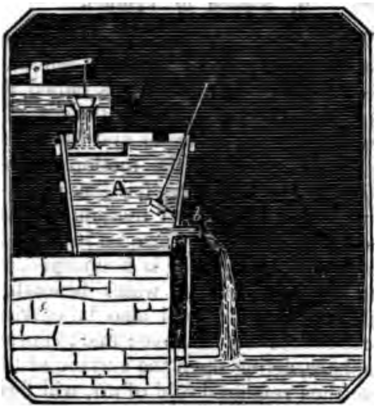
A model of the Siphon of Venturi is represented in Fig. 60, on page 196.

6. *Hydraulic Ram.*

214. The plan of the Hydraulic Ram was derived by Mongolfier from the observation of the following fact: If water running freely through a pipe have its current suddenly checked by closing the end whence it is discharged, and there be a small hole on the upper surface of the pipe near this end, a jet or stream of water will suddenly spout through this

* See Mechanics, § 399.

Fig. 60.



A is a vessel constantly full of water, which flows off through the pipe C.
b b is a siphon introduced into that part of the pipe C in which the *vena contracta* forms.

hole to a height much greater than that whence the velocity of the water in the pipe is derived. This jet will only continue for a short time, and will gradually decrease in height until that amounts to no more than the effective head of water. By opening the pipe again, and thus permitting the water in it to resume its original velocity, the operation may be repeated. The cause of the rise of the water from the small hole is, that the velocity being suddenly checked, the whole quantity of motion of the water in the pipe is exerted to force a part through the small opening; and abstracting from friction and other resistances, the height of the jet will bear to the effective head of the water in the pipe, the relation that the area of the latter bears to that of the former.

In order to render this principle efficient in practice, it is necessary to cause the water to rise in a pipe instead of a jet in the open air; to place a valve on this rising pipe, in order to prevent the return of the water it contains, when the water in the main pipe resumes its flow; and to adapt a self-acting valve to the main pipe, by which it may be opened and shut alternately. The latter object is attained by the application of a simple principle. Water, when in motion, is capable of carrying along with it bodies of greater density than itself, and of sizes having relation to their own density and the velocity of the water. Thus large and heavy masses of rock are swept along by torrents; rounded stones, pebbles, and gravel by streams of less intensity. On the other hand, as soon as the velocity is checked, such substances are deposited, in consequence of their superior density, which causes them to sink. A valve constructed upon this principle will not open immediately after it closes, but will remain shut an appreciable time, because a body in motion does not immediately lose all its velocity, but must pass through every intermediate rate of motion from its maximum to 0; and the valve does not forthwith close, because it requires a definite time for a body at rest to resume its previous velocity. The latter part of the principle may be illustrated by a number of facts: a cannon ball will strike a mark as certainly if fired from a piece suspended freely on a pivot, as if fired from one firmly fastened down, because there is not time for the motion to be communicated throughout the whole body of the piece before the ball leaves the muzzle; a person who passes rapidly over thin ice or a weak board, may do so without breaking them, while, if he move slowly, they are infallibly ruptured; a rope tied to a shell which is fired from a mortar

is broken, however freely it may be coiled, because the motion has not had time for its transmission throughout the whole length.

It was, moreover, found that the sudden action, by which the jet is caused to rise, was apt to burst the rising pipe or force water through its joints. To prevent this, an air vessel was placed on this pipe, the air contained in which should act as a spring to regulate the action, and cause a continual, although not a steady, flow of the water in its ascent.

These facts and principles being premised, the structure and action of the instrument may be understood. (See Fig. 61, on page 199.)

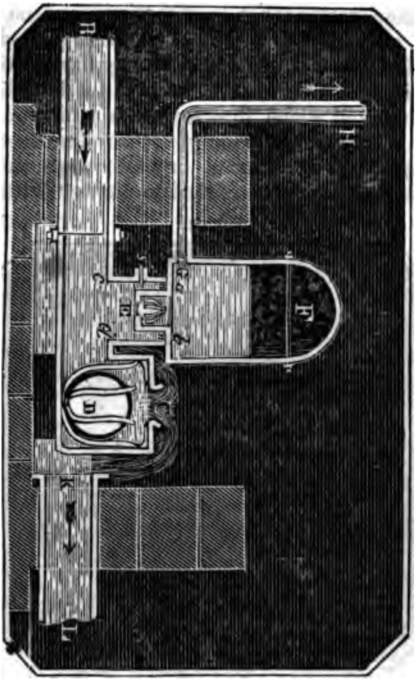
The Hydraulic Ram is liable to difficulties in its action, in consequence of the tendency which air has to mix with water. That which is contained in the airvessel may therefore be finally exhausted, and the action of that part of the engine may thus cease. To remedy this defect, valves have been planned by which new supplies of air may be obtained from the atmosphere.

7. *Pumps.*

215. The principle on which the common pump acts forms a part of the theory of Mechanics.* It is sufficient for our purpose to recollect that water is forced by the pressure of the air into a pipe which would otherwise become a vacuum, in consequence of the alternating action of a piston furnished with a valve opening upward. The reflux of water is prevented by a fixed valve, also opening upward. Pumps of the common kind, therefore, rather differ from each other in the material of which they are constructed and the form of the valves, than in any other respect.

* See Mechanics, § 358.

Fig. 61.



B, a pipe through which water is flowing from a millpond or reservoir. This is bent upward at right angles, and the water, if unobstructed, would be discharged at C. In the bend of the pipe is a valve, D, of a spherical figure, of such weight as to sink in water, but not so dense that it will not rise when the water in the pipe B has acquired all the velocity which is due to its effective head.

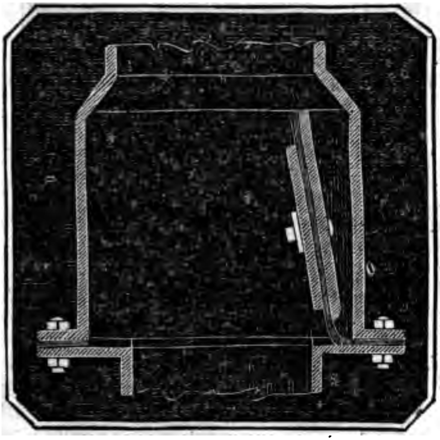
a b c d is a short pipe adapted to the pipe B, and directed upward. In this pipe is situated a valve, E, also of a spherical figure. This alternates in its motion with the valve D, closing the passage *a b* when C is open, and opening when it shuts.

F, air vessel.

G H, ascending pipe, in which the water is raised by the tension of the air compressed in the airvessel F.

(1.) The valves of the cheapest form of the common pump, represented in the figure, are no more than a circular plate of leather, on a part of the circumference of which is a rectangular projection, which is nailed down to a collar in the barrel or in the piston, and which thus serves as a hinge. The leather is stiffened by nailing a piece of wood on the lower side. India rubber, or cloth prepared with that substance, has been found to answer better.

Fig. 62.



(2.) A circular plate of leather may be nailed in the direction of one of its diameters to a bar which crosses the barrel of the pump, or the hollow of the piston. This valve, from a resemblance in its motion to that of wings, is called the butterfly valve. It may also be executed in metal, in which case the two parts have the shape of a portion of a circle *somewhat less* than a semicircle, and are connected

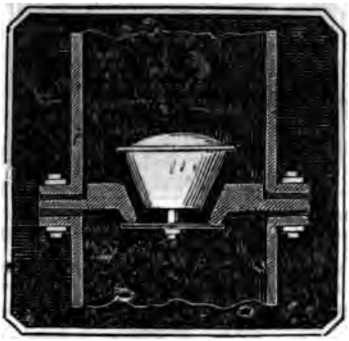
with the bar by a hinge. This form of valve has already been spoken of as that used in the airpump of a steam-engine.

(3.) When the body of the pump is a square, a valve, called, from its figure, pyramidal, is sometimes used. This has for its basis a frame having the form of the four edges of a regular pyramid. The moveable parts of the valve are four equilateral triangles of leather, stiffened by wood, and nailed at the base of the pyramid.

(4.) The triangular valve is applied to a pump whose body is also square. The seat of the valve is composed of two equilateral triangles, which, when introduced into a square, lie in an inclined position. The leather plate has the same figure, and is nailed to a diagonal bar.

(5.) The conical valve (Fig. 63) is always made of metal, and has the shape of the frustum of a cone,

Fig. 63.

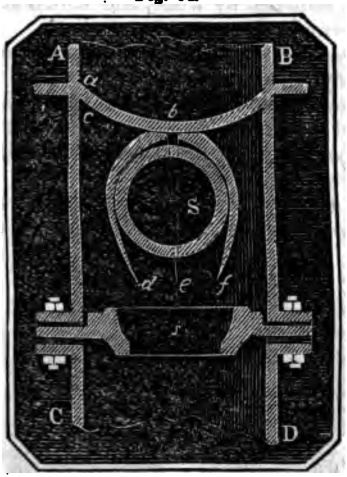


adapting itself to a seat of the same figure. This valve requires to be guided by a rod passing through a bar fixed in the body of the pump or in the move-

able piston. This valve, which is among the best when the water is clean, is liable to be choked by the entrance of solid matter.

(6.) The spherical valve is a hollow sphere of metal, which applies itself to a seat having the figure of a zone of a sphere. This valve is represented in Fig. 64.

Fig. 64.



A B C D, Barrel of the pump.
s, Valve seat of the figure of a zone of a hollow sphere.
S, Valve of the figure of a sphere.
a b c, Bar extending across the pump barrel, to bear flexible strips of metal which keep the motion of the valve within proper limits.
b d, *b e*, *b f*, Flexible strips of metal.

This valve is less liable to choke than the conical valve, and may be rendered almost incapable of being choked by adapting a long rod to it, and loading

the end of the rod with a weight. With this addition the cage becomes unnecessary, and it is now called the pendulum valve.

Such are a few of the many forms which have been proposed for the valves of pumps.

216. The common pump is an apparatus of great convenience, and, wherever the quantity of water required is such that the expenditure of the moving power may be disregarded, is, perhaps, the most useful of all hydraulic engines. Even in such instances it is limited in its use by the fact that the rise of the water is due to atmospheric pressure, which, unless the materials and workmanship are superior to those usually employed, cannot be relied upon if the height of the lower valve above the water to be raised exceeds 28 feet.

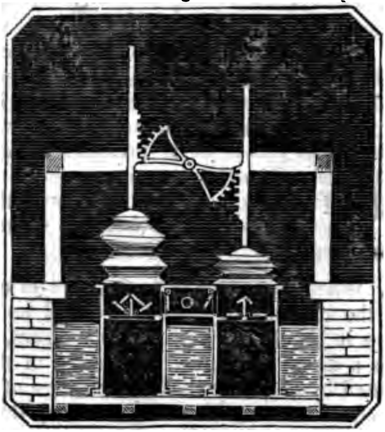
217. When the pump is to be kept in continued action, the quantity of force which will be required to move it becomes an important object, and the pump is a disadvantageous application of the force. It is stated by Hachette that the measure of its work is not equal to more than one tenth of that of the prime mover.

When a common pump is worked by men, the application of the force is still more disadvantageous; for the particular manner in which a man works the brake of a pump constitutes a labour which exhausts more rapidly than almost any other. There are, notwithstanding, cases in which no adequate substitute has been introduced into general use.

The great friction which attends the motion of the piston of a pump, when packed in such manner as to be air tight, is one of the causes of the loss of force. It has been attempted to obviate this by enlarging the *part* of the pump in which the piston acts, and

connecting the piston to the seat of the lower valve by a hollow vessel of leather. The best form of this is made up of a number of rings of leather united at their outer edges. We annex a draught of such a pump taken from the work of Hachette.

Fig. 65.



This has recently been published in this country as a new invention.

Martin's ship pump is somewhat similar. The *pompe des pretres* has its moveable valve situated in a loose diaphragm of leather, placed in an enlargement of the body of the pump.

218. It is a common mistake to suppose that, as the moving power in the common pump is the pressure of the atmosphere, there is but little force employed to move it. But this pressure is no more than a machine interposed between the prime mover and the water to be raised, and does not act of itself.

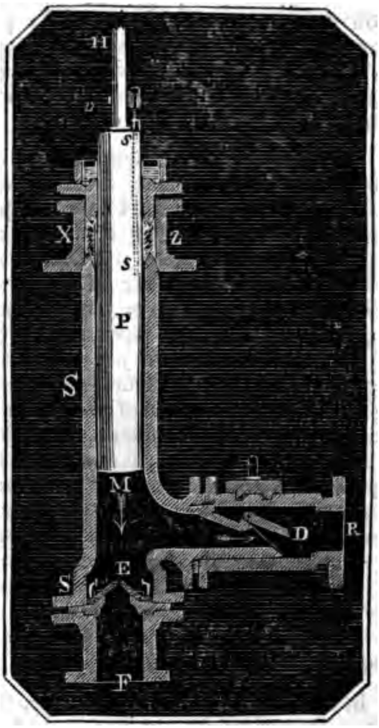
In order to bring the pump into that state in which water will flow at a single stroke of the piston, as much force must have been previously applied, in addition to that intended to overcome the friction, as would raise the water to the level of the lower valve in any other way.

219. The common pump being limited in its action to heights which, under the most advantageous circumstances, do not exceed 34 feet, pumps of another description, called forcing or lifting, are used where the height to which the water is to be raised exceeds that limit. The latter of these is rarely used. The former differs from the common pump in having a solid piston. A pipe proceeds from the body of the pump, at a point just above the fixed or lower valve. This pipe is furnished with a valve opening upward. The action of the piston in rising is similar to that of the common pump; but on its descent it forces, first, the air contained in the body of the pump, and subsequently the water raised by its previous action, through the last-named valve into the pipe we have described. The previous action has the same limit as the common pump, say, under ordinary circumstances, 28 feet; but the latter action has no limit except the strength of the materials of which the pump is constructed, and the intensity of the agent employed to work it.

220. In the best form of forcing-pump, the piston does not work against the sides of its body, but has the form of a plunger, which is passed through a collar that closes the upper part of the body of the pump. With this form of piston, the friction of the pump is considerably lessened.

A pump of this form is represented in Fig. 66, on the following page.

Fig. 66.



S S. Body of the pump.
P M. Solid plunger.
H. Pump-rod.
E. Suction valve.
D. Force Valve.
R. Rising pipe, through which the water is forced up when the plunger descends.
F. Pipe through which the water rises by the pressure of the atmosphere when the plunger is drawn up.
X Z. Collar enclosing a packing of oiled leather, by which the joint between the barrel of the pump and the plunger is rendered air-tight.
s s. Channel by which any air that may lodge in the pump can be permitted to escape.

As the friction of a pump of given dimensions is a constant quantity, the force required to overcome this resistance in a force-pump, raising water 28 feet by the pressure of the atmosphere, and 28 feet by the forcing action, is no more than in a common pump; and with every increase in the height to which the water is raised, the proportion between the useful action of the prime mover and the loss by friction will be lessened. A force-pump, therefore, which raises water to a great height, is a much more advantageous application of a prime mover than the common pump.*

The action of the force-pump is regulated by the addition of an airvessel. This is placed upon the pipe through which the water is raised. The rea-

* Pumps are worked to greater advantage by the steam-engine than by any other agent. In fact, the reciprocating motion of the engine, which corresponds identically with that of a pump, was originally contrived for this very object, and the successive changes in the structure of the engine have taken the character merely of improvements. In the use of pumps of large size driven by a steam-engine, it has been found that the stroke of the piston must not exceed 8 feet. The proper velocity in feet per minute will be found by multiplying the square root of the length of stroke by the constant number 98. The quantity of water in cubic feet per minute is found by the continued multiplication of half the velocity of the piston in feet, the square of the velocity in inches, and the constant fraction 0.00518.

The diameter of the piston of the pump in inches is found by the formula

$$d=\sqrt{3.15\ W};$$

in which W is the quantity of water to be discharged in cubic feet.

The corresponding diameter of the piston is found by the formula

$$D=\sqrt{\left(\frac{.7332\ W\ H}{p}\right)};$$

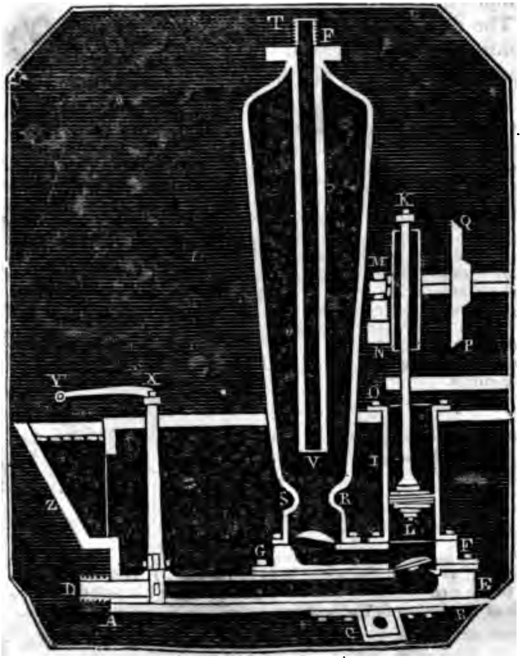
in which p is the average pressure on the piston, and H the effective height to which the water is to be raised. H is found by adding to the real height $1\frac{1}{4}$ feet for every separate lift, and one twentieth of the length of the pipes of which the pump is composed.

sons for using an airvessel in the hydraulic ram are applicable in this instance also.

221. The common fire-engine is composed of two force-pumps, which throw water into a single air-vessel. The two pumps are connected by a brake or lever, having a fulcrum lying between them; they therefore act alternately, and the action of the air-vessel produces a constant stream.

Fig. 67 is a section of a fire-engine, exhibiting one of the pumps.

Fig. 67.



L is the piston of the pump, the rod of which is attached to a circular segment, K N.

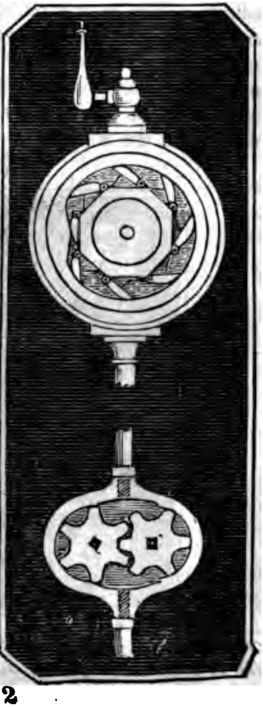
The lower or suction valve is opposite F.

The valve G forms a communication with the large airvessel, whence the water is forced, by the elasticity of the compressed air, through the pipe V.

At T is a screw to which a hose or pipe may be applied.

At D is a screw to which a hose may be adapted, through which water is forced by the pressure of the atmosphere to the valve E. The pipe which conveys the water from the hose to the valve may be closed by a stopcock, which is turned by the lever Y X; and when this communication is closed, one is at the same time opened with a cistern, which is formed by a box enclosing the pumps and valves. This cistern may be filled from a grated opening above the inclined side Z.

Fig. 68.



222. The defects of the common pump have led to the invention of rotary pumps. In these the valves work in a ring; the water enters on one side of the ring, and is forced out at a point nearly opposite. A rotary pump may act as a common or forcing-pump, according to its position. Of rotary pumps there are several varieties, but the friction in any of them is far less than in either the common or forcing pump. It would, in consequence, be a great saving of labour could the rotary pump and apparatus for working it be applied to a carriage, in order to serve as a fire-en-

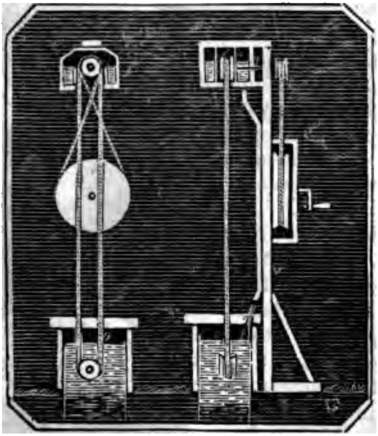
gine. Sections of two rotary pumps are represented in Fig. 68, on page 209.

Among other forms which have been proposed to remedy the defects of the common and forcing pumps, are that of Vera, and the centrifugal pump.

8. *Pump of Vera.*

223. The pump of Vera is composed of an endless rope stretched in a vertical position between two pulleys. The upper pulley is made to revolve by a winch, or by bands passing over wheels, so arranged as to increase the velocity of the motion, and the rope will revolve with the pulley. The lower pulley is situated in the reservoir whence water is to be raised, and the rope, in turning under this pulley, be-

Fig. 69.



comes charged with the fluid, which it carries up with it until it is in the act of passing over the upper

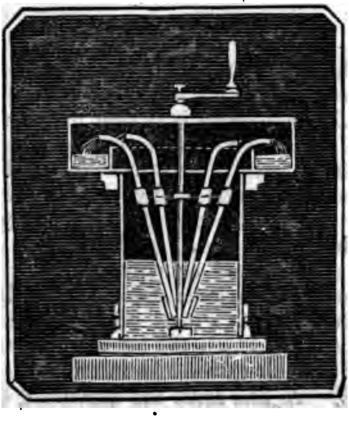
pulley. In this change in the direction of the motion of the rope the water does not immediately participate, and is therefore thrown off. The water thrown off is received in an appropriate vessel, whence it is discharged by a spout.

The efficient action of this pump depends upon the degree of tension of the rope. If this tension be too great, the friction will require too great a part of the moving power; while, if the tension be too small, the rope will slide. The greater velocity of the rope, the more of the water which the rope takes up will be carried with it to the upper pulley. Ropes made of hair are found to carry more water than those of hemp.

9. *Centrifugal Pump.*

224. In the centrifugal pump a number of pipes are arranged on the surface of a truncated cone, whose least base is lowest. The upper part of each

Fig. 70.



pipe is bent outward, and then turns downward for a short distance. When a rapid motion of revolution is given to the cone, the centrifugal force will cause any water with which the pipes are loaded to be discharged at their upper orifice; and if the lower end be immersed in water, a column of that liquid will continue to flow upward through the pipe.

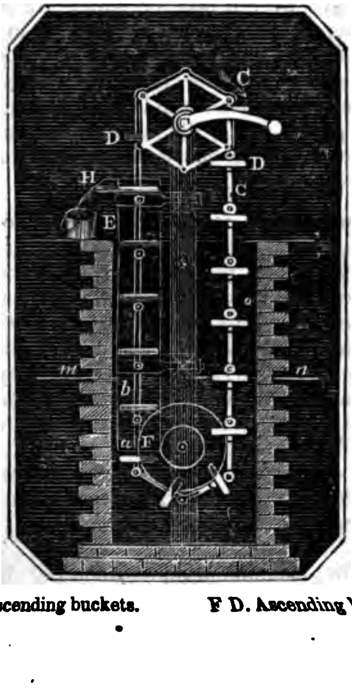
This kind of pump is principally worthy of notice as an illustration of the mistakes which may be made in mechanics even by intelligent men; for it has been maintained by some, that as the force in compliance with which the water is discharged is a consequence of the rotation, more water might be raised than would be equivalent to the energy of the prime mover. Those who reasoned in this way forgot that the centrifugal force is, in fact, the force to which the revolution is due, and derived immediately from the prime mover, whose intensity it therefore can never exceed, but will be always as much less as is due to the friction and other resistances.

10. *Chain-pump.*

225. The chain-pump is composed of an endless rope or chain, to which a number of buckets are attached. This apparatus is passed over a fixed pulley, which is caused to revolve by the prime mover, and carries the chain of buckets with it. The buckets may be open vessels of any form, or they may be merely flat boards, through the middle of which the rope or chain is passed. In the former case, the pulley is either round or polygonal, having sides equal in length to the links of the chain. In the latter case, the pulley is a mere skeleton composed of six radii, between which the buckets fall, and which are forked at their extremities in order to take hold of the chain. In this form the ascending branch of

the chain passes into a barrel, which its buckets nearly fill at the lower end, but which is enlarged towards its upper end, in order that there may be no risk of the buckets touching it. The lower end of the barrel is immersed in water; and, when the chain is set in motion by turning the pulley, water will be forced into the barrel by each bucket, the greater part of which will be carried through the barrel and discharged at its upper end. A chain-pump of this form is represented Fig. 71.

Fig. 71.



C C. Descending buckets. F D. Ascending buckets.

E. Pump barrel through which the ascending buckets rise; the lower bucket entering at *a*, and the upper bucket discharging the water taken up at *b* through the spout H.

m n. Level of the water in the reservoir.

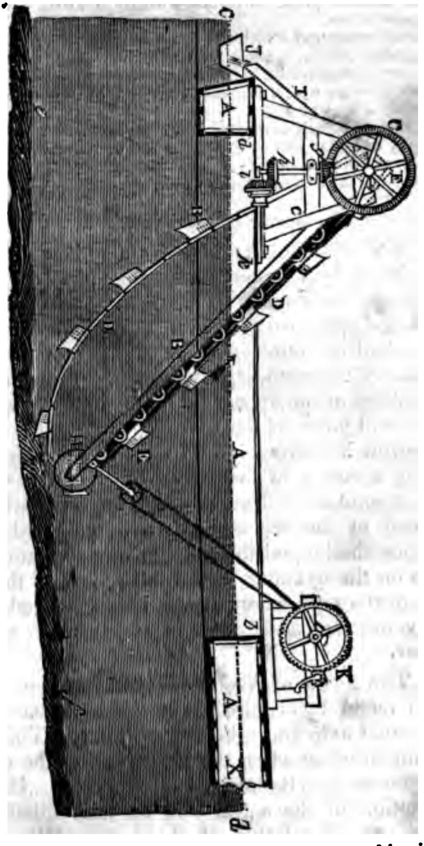
When a chain-pump is worked by the force of men acting upon two winches on opposite sides of the axis, the quantity of water raised has been found equal to three fourths of the measure of human force given in § 31.

226. It is sometimes necessary to place a chain-pump in an inclined position, in order that water may be discharged over a dike or bank. In this case, the rising branch of the chain-pump lies in an open inclined channel, and the lower face of the buckets touches the bottom of this channel. A greater friction than in the vertical form is the consequence, and the work performed is diminished to seven tenths of the measure of the moving power, when men or animals are employed.

227. An inclined chain-pump, formed of strong scoops attached to a chain, and passing over a polygonal pulley, is now used in the operation called dredging, or the removal of loose matter from the bed of streams. This may be set in motion by a steam-engine, or by horses. The first application of the chain-pump to this purpose was made by Evans, in 1801, on the Delaware. This experiment is the more remarkable, as it was accompanied with the successful propulsion of the vessel on which the machine was erected, by means of the steam-engine, not only through the water, but along the ground which intervened between his workshops and the river.

A dredging-machine is represented Fig. 72, opposite.

Fig. 72.



A A A. Section of the vessel on which the machine is placed, having a well in the space d k, through which the chain of buckets works.

D D. Chain of buckets.

C B H. Inclined plane furnished with rollers, over which the loaded buckets rise.

F H. Pulleys around which the chain of buckets turns.

k l, *h g*, &c. Shafts, wheels, and pinions through which the prime mover is transmitted to the pulley F.

I. Spout through which the matter raised by the machine is discharged into a barge J.

K. Pinion and wheel, connected by a rope and pulley E with the pulley H, by means of which the lower end of the chain of buckets is set to the desired depth.

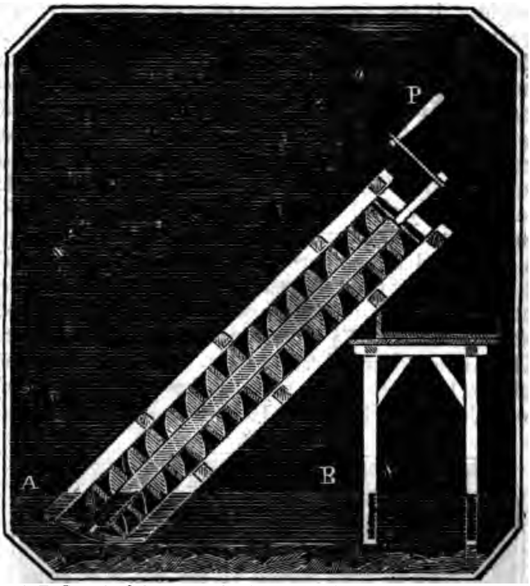
d. Level of the surface of the water.

11. *Screw of Archimedes.*

228. The screw of Archimedes may be conceived to be formed by wrapping a flexible pipe around a solid cylinder, in the form of a screw. This cylinder is supported upon two gudgeons, in such manner that its axis shall be more inclined to the horizon than the thread of the screw is to this axis. If, therefore, the lower end of the apparatus be immersed in water, that fluid will enter at the lower opening of the pipe. If the screw be turned on its axis in the direction by which a screw is forced downward, the water which has entered will move along the inclination of the thread of the screw, and when the number of revolutions shall equal the number of convolutions of the pipe on the cylinder, it will have risen to the upper end of the pipe, where it will be discharged. At each revolution an additional quantity of water enters the screw.

229. The screw of Archimedes, in its more usual form, is made by enclosing a spiral surface between a solid axle and a hollow cylinder. This has its maximum effect when the lower end of the cylinder is immersed to its horizontal diameter. Half of a convolution of the spiral will be thus filled with water at each revolution of the axle. When the water in the reservoir has a varying level, it has been found better to omit the hollow cylinder, and

Fig. 73.



A B. Level of the water in the reservoir.
P. Winch or handle by which the screw is turned.

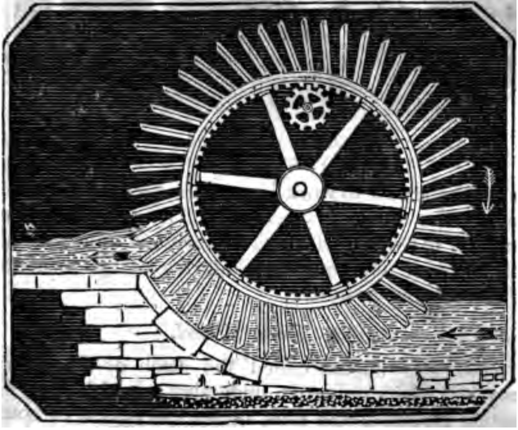
cause the screw to work in an open inclined channel, having the shape of the half of a cylinder. The quantity of work performed by men and animals with this machine is about three fourths of the measure of the moving power.

12. *Flash Wheel.*

230. The engine called the flash or fen wheel may be considered as an undershot wheel having its motion reversed, and thus, under the action of some

prime mover, raising a current of water up a small height. It has the advantage of great simplicity, and is attended with little friction. In its best form it is placed in a channel which is nearly filled by its buckets, like the modification of a breast-wheel represented in Fig. 17; and its buckets are so placed as to be vertical at the time the water is discharged from them into the horizontal channel which is to carry it off. This apparatus has been for ages advantageously used in Holland, for draining the surface-water off embanked meadows. In that country it is moved altogether by windmills. In England it has recently been moved by steam-engines, and, in late experiments, an engine of 80 horse power raised 9840 tons, 6 feet 7½ inches in the space of an hour. This is equivalent to 29,164 lbs. raised one foot per minute by each horse power; the consumption of coals during the hour was 10 bushels. The form and

Fig. 74.



character of this flash wheel may be understood from Fig. 74.

231. We have given but a small selection of the almost innumerable forms of engines for raising water. Among those which remain are the Tympanum and Noria, of ancient celebrity. Since the introduction of the use of steam, there has been but little need of directing attention to these instruments, once of great note.

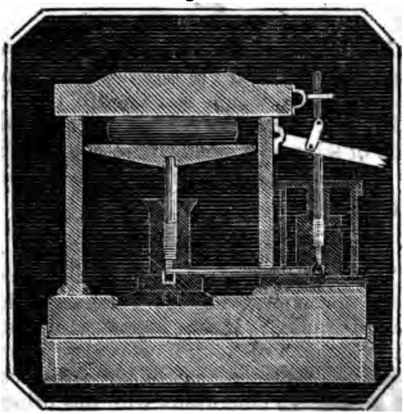
13. *Hydraulic Press.*

232. The hydraulic press depends upon the principle in the mechanics of fluids which is called the hydrostatic paradox. It thus happens, that the pressure of any column of fluid, however small, may be made to counterbalance that of any other column, however great. In conformity with this principle, if there be a communication between two columns of the same fluid, whatever pressure may be exerted upon the one will be transmitted to the other, in a ratio proportioned to the respective area of the two columns.

In the hydraulic press, a small pump, with a solid plunger, is made to force water into a cylinder of much greater diameter than itself, and in which a solid plunger is also placed. The quantity of pressure which is thus transmitted to the latter, is as much greater than that which the prime mover exerts upon the piston of the former, as the area of the former is greater than that of the latter. When this instrument is applied as a press, it has the form of Fig. 75, on page 220.

233. The increase of the intensity of force by means of the water-press exceeds any that can be produced in other ways, except by a complex ar-

Fig. 75.



rangement of machinery. It has therefore been applied to many other purposes than mere pressure. Thus, it is employed to prove steam-boilers, water-pipes, and cannon; to tear up the roots of trees; to draw piles, after the purpose for which they were driven has been accomplished. In proving cannon, it has been found not only to have the effect of showing any flaws which may exist in the casting, but also to remedy them. It has, in fact, been observed, that after a cannon has been made to leak under the action of the water-press, it has, on renewing the same proof after an interval of some days, become tight. The explanation of this is to be found in the action of the water forced in among the crystalline particles of the iron, to rust their surfaces, and thus unite them by a ferruginous cement.

The hydraulic dock, which has been mentioned in *§ 197, is a* beautiful application of this machine. A

platform of sufficient size to receive the ship, and strong enough to bear its weight, is suspended by a number of chains, which are attached on each side of the platform to a horizontal beam. Each chain touches a pulley, over which it is bent when the beam is drawn forward, and the chains drawn by the beam over these pulleys lift the platform. The two beams are drawn forward by the great piston of a hydraulic press, which works in a horizontal cylinder. The force-pump of this press may be worked by steam. By means of the press a small force has its intensity so far increased as to lift the largest vessel. In the port of New-York, vessels of 1000 tons burden have been lifted by this apparatus.

In the above list we have included some of the more important or interesting hydraulic engines. The number which have been proposed or actually introduced is so great that even to name them would exceed our limits.

X.

EQUILIBRIUM AND MOTION OF VESSELS.

234. However irregular may be the figure of vessels intended for navigation, the theory of their equilibrium is easily reduced to the general principles of Mechanics, in consequence of certain circumstances in their structure, and in the position where they are placed. It is necessary, in investigating the conditions of equilibrium, to have three planes perpendicular to each other, given in space, as one of the conditions of the problem. Three such planes are determined in every vessel:

(1.) All vessels are so built that their opposite sides are symmetric, and in loading great care is taken to distribute the weight equally. The two symmetric parts are divided from each other by an imaginary plane passing through the middle of the keel. This is called the diametrical section, or plane of the keel.

(2.) The vessel floats at the surface of the fluid, having a part of its hull immersed. This immersed part is equal in volume to a mass of the fluid whose weight is equal to that of the vessel; and this part may be conceived to be separated from that not immersed, by a plane formed by supposing the surface of the fluid to be produced through the body of the vessel. This plane is horizontal, and perpendicular to the plane of the keel.

The part immersed is called the *hollow* of the vessel, the plane which separates it that of flotation.

(3.) The point of application of the resultant of *the fluid pressure* which acts upon the outer surface

of the hollow, is situated in the centre of gravity of the displaced fluid, or in that of the hollow, considered as homogeneous. This force is in equilibrio with the weight, and the centre of the hollow must therefore lie in the same vertical line with the centre of gravity of the vessel. Both these points are situated in the plane of the keel, and a plane passed through them perpendicular to the keel will be vertical, and also perpendicular to the plane of flotation.

The plane thus passed through the two centres corresponds nearly with the greatest transverse area of the vessel, which is called the midship section, and we may, without error, consider them as being one and the same.

235. In consequence of the usual figure of the hollow, which is much fuller near the midship section than at its extremities, it happens, that, although the whole weight of the vessel is in exact equilibrium with the buoyant forces, the partial weights and partial buoyant forces which act upon any given portion of the surface of the hollow are not in equilibrio. If, therefore, as is the fact, the materials of which a vessel is constructed are neither rigid nor perfectly well fastened together, there must be a tendency to bend under the varying action of the two forces.

The manner in which this occurs may be understood from the following explanation. Fig. 76 represents a section in the plane of the keel of a vessel of the usual figure; g is the centre of gravity, h the centre of the hollow; if each of these forces be considered as made up of two parts, divided in their action from each other by the midship section $m\,s$, the centres of action of the weight will be at points such as g' and g'', while the centres of the buoyant forces will be at points such as h' and h'', nearer to the midship section than g' and g''. It will there-

Fig. 76.

fore be obvious, that the weight acts at a mechanical advantage upon the arm of a lever longer than that on which the buoyant force does. The tendency to bend the vessel growing out of this cause, were we to resolve the weight and buoyant forces into a greater number of partial forces, would be still more obvious. For it would then be apparent that, at the midship section and its neighbourhood, the buoyant force is in excess, while towards the stem and stern it is more and more in defect. All vessels, therefore, which are of such a figure as to possess good properties as sailers, which we shall find requires them to be sharp both fore and aft, have a tendency to bend, by rising in the middle, and sinking at the ends. This tendency produces in all large vessels a change of figure, which is called *hogging*.

While the vessel lies upon the stocks, and the keel is equally supported throughout, the tendency to bend does not take place; but the forces which cause it are called into action at the instant of launching, when the vessel is for the first time water borne. Even in this act, and before any additional weight in the form of equipment,

armament, and stores has been taken on board, the bend in the deck of a 74 gun ship has been found by observation to be as much as 8 inches. The bending force acts upon the vessel during its whole duration, and is the most efficient cause of the rapid rate at which ships of war cease to be serviceable. It is at any rate certain, that wood which will, in a good mechanical combination, retain a sufficient degree of strength for ages on the land, soon becomes so weak in a vessel, even without rotting, as to require to be replaced, or the vessel to be condemned as not seaworthy.

The longer the vessel and the more acute its extremities, the greater will be the tendency to hog. This tendency may be partially met in the stowage of vessels, by placing the greatest weight near the midship section, and leaving the parts near the stem and stern free from lading. But this method is rarely practicable even in merchant vessels, and in ships of war is out of the question, because their armament, which forms a large portion of the weight they carry, must be distributed with uniformity.

236. Vessels are usually constructed of a number of frames of timber at right angles to the plane of the keel. These are bound together, and the hull rendered water-tight by a series of planks, which cross the midship section at right angles, and the other frames at angles more or less acute as they recede from that section. Farther strength is attempted to be given by a series of planks, called the ceiling, which lie parallel to the former, on the inside of the frames. The frames and planks, in crossing each other, therefore formed figures differing but little from a parallelogram, and are under the circumstances of a gate without a diagonal brace, or a door without panels. Both of these structures, as

is well known, would speedily lose their original figure, and finally fall to pieces under the action of their own weight. In the same manner, a ship tends to bend, and is finally destroyed, by the excess of the action of the weight over that of the buoyant force, at points distant from the midship section; and this tendency is not met, as in the gate, by diagonal bracing, or in the door, by filling up the frame with panels.

The simplest mode of obviating this defect would, we conceive, have been that long adopted in the gates of canal locks, in which the planking is often placed in a diagonal position. In imitation of this, it would have been sufficient to have laid the ceiling planks in a diagonal position, inclining downward in both directions, from the midship section towards the stem and stern.

Seppings, a British naval architect, in the year 1812, proposed another method founded on the same principles. He suppressed the ceiling plank altogether, substituting for it a series of diagonal timbers extending each way downward from the midship section. Above the main-deck he introduced shorter diagonal braces, and even the planking of the decks was laid diagonally.

He, in addition, proposed to introduce the principle of the panel, by filling every vacant space with pieces of timber. In many of the British ships also, the frames, which have usually spaces between them, were made to touch, so that, by calking, they might be rendered water-tight. This, however, rather adds to the inherent defect of vessels. It did not occur to Seppings that, in the works of nature and in the most skilful productions of human art, strength is gained in two ways, namely, by a better arrangement of their *materials*, and by diminishing their weight as much

as possible. It cannot be doubted that the quantity of timber which is employed in the structure of a vessel is far more than is suffioient for strength, were it skilfully distributed and arranged. Much therefore remains to be done towards the perfection of naval architecture, which, so far as resistance to flexure is concerned, had remained in the same state from its earliest origin to the time of Seppings.

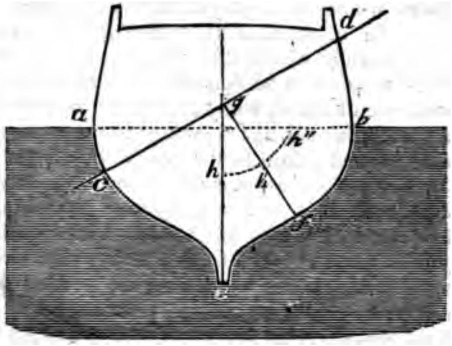
The success of Seppings's method is, notwithstanding, such that, in a seventy-four gun ship, the bend of the deck which takes place in the mere act of launching was reduced from 8 inches to 2 inches. Subsequent experience has shown the greater durability of vessels built on his construction.

At present, diagonal braces of iron are much used instead of the diagonal timbers of Seppings.

237. The equilibrium of a vessel, under the action of the weight and the buoyant force, is not permanent, but is liable to be disturbed by the action of the wind upon its sails, or by the oscillations of the fluid on which it floats. Now the centre of the hollow lies in all cases below the surface of the water, and the centre of gravity is most frequently above that surface. The point of support being thus below the point at which the weight acts, the condition would be that of tottering equilibrium, were it not for the circumstance we shall explain.

In the vessel whose midship section is represented Fig. 77, the respective centres of gravity and of the hollow are at the points *g* and *h*. Let us suppose the vessel to be inclined in such manner that the level of the surface of the fluid no longer corresponds with the line *a b*, but with *c d*. It will then be obvious, that while the line of direction of the centre of gravity has changed in its relative position in the vessel from *g e* to *g f*, the centre of the hollow will have

Fig. 77.



moved outward towards the side *b d*. If it have changed its position to a point such as *h''*, which is more distant from the plane of the keel than the line of direction *g f*, the buoyant force will act at a mechanical advantage over the force of gravity, and the vessel will tend to return to her original position. But if the point *h'* fall in the line *g f*, then the two forces will still counterbalance each other, and there will be no tendency to return. If, again, it should fall between *g f* and *g e*, the weight will act to a mechanical advantage, and the condition will be that of tottering equilibrium, under which the vessel could be upset. It will easily be seen, that by a proper construction of vessel and distribution of the cargo, the first of these conditions may be attained, namely, that when the vessel is caused to incline by the action of an extrinsic force, the buoyant pressure of the water may for a time be made to act more forcibly, and thus the vessel be caused to return to her primitive position; here the two forces are again in equilibrium, and thus the vessel will continue to perform a

series of oscillations from side to side, an act which is called rolling. When the disturbing force is that of the wind acting upon sails, the return towards the original position is aided by the fact that the wind acts less directly on the sails when the vessel is inclined, and its centre of action is nearer the horizontal surface, in consequence of which its intensity is diminished, as upon a lever of a shorter arm.

It may, however, happen, that in any vessel whatsoever, the effect of the wind on the sails may be such, that if they do not themselves give way, the vessel will be carried beyond the point at which the relative motions of the centre of the hollow and of the line of direction of the centre of gravity will fulfil the required condition. From the position, almost vertical, in which the timbers on which the decks lie are now placed, the vessel is said to be thrown on her beam-ends, and has no longer any tendency to return to an upright position. There is, however, a remedy which is within reach. The condition of stability will be resumed by lowering the position of the centre of gravity, and this may be done by getting rid of the weight of the masts, sails, and rigging. For this purpose it is not necessary to cut away the masts. These are so large that their respective strength is not sufficient to resist the action of their own weight. They would therefore break when lying in a horizontal position, were they not strengthened by the cordage known by the name of lanyards. It is sufficient to cut these on the upper side of the mast, and the latter, being no longer supported, will give way.

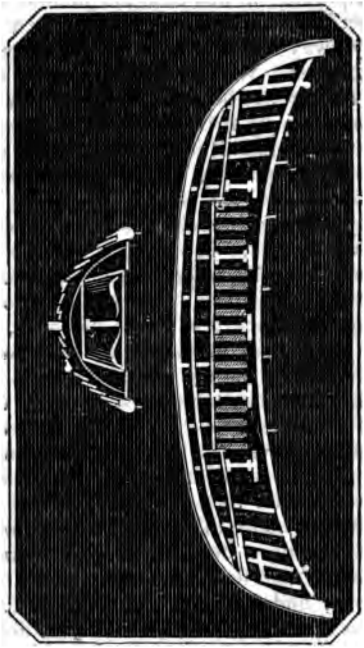
238. In the act of rolling, the centre of the hollow revolves around a point which is called the *metacentre*, and the greater or less stability of the vessel will depend upon the position of this point. The higher

this metacentre is situated, the greater the stability. The metacentre may be raised, and the stability enhanced, by increasing the breadth of beam, and by making the extreme breadth of the vessel lie higher than the level of the surface of the water. The stability may also be increased by lowering the position of the centre of gravity, when this can be done without increasing the weight with which the vessel is loaded beyond proper limits. When, however, a vessel is so deeply laden that the draught of water exceeds half the breadth of beam, or when the extreme breadth is immersed, the advantage derived from this source ceases.

Analysts have shown that the stability will be greatest when the curves drawn on the bottom of the vessel are circles whose centre lies in the point of application of the disturbing forces. This figure cannot be given when the disturbing force is the wind applied to sails, but may be used when the oscillations are principally due to the waves. Figures of this description are to be found in portions of the rind of a cocoanut or of the skin of an orange; and these, when thrown upon the water, will float with their pointed ends upward, whatever be the violence of the winds and waves. Upon this principle Mr. Greathead constructed his life-boat, of which Fig. 78 is a draught.

This vessel, it has been found, cannot be upset. Nor can it sink, because all the space beneath the seats, and at the bow and stern, are filled in with cork, which has so little density that the life-boat, when loaded with as many persons as it can carry, and when all the vacant space is filled with water, is still buoyant. Airvessels might be substituted for cork, but are liable to injury; and a patent has recently been taken out for using vessels filled with hy-

Fig. 78.



drogen gas, in order to render a life-boat buoyant. This method, however plausible, is of little or no value, for the difference between the weights of these bulks of common air and hydrogen, however different their densities, does not bear a sufficient proportion to the whole weight of the vessel, to make any important difference in its buoyancy.

239. When a vessel has masts and sails, it is not advantageous to increase the stability beyond a cer-

tain limit, because in this case the motion of rolling will be performed with a degree of violence which may carry away the masts, or may even cause the vessel to founder. With an equal degree of stability, the act of rolling may be performed in different times, and, the more slowly it is performed, the less will be the danger with which it is attended. The centre of gravity and the quantity of the vessel's lading remaining unchanged, the velocity of rolling may be lessened by stowing the weight as far as possible from the plane of the keel. A knowledge of this fact has led to some important improvements in seamanship and in naval architecture. Thus, in ships of war, it is no longer customary to house the guns, as it is styled, or draw them in board for the purpose of shutting the ports; but the ports have holes in them, and are fitted with tarpaulin cases, in which the muzzles of the guns are enclosed. So also the transverse section of large vessels has been in some cases changed, and always with advantage. These sections formerly, after rising to their extreme breadth a short distance above the load-water-line, fell rapidly inward, forming a concave curve. In the U. S. ship Ohio, for the first time, this method was departed from; and, although the width of the spar-deck is less than the extreme breadth, the diminution is effected by means of a convex curve.

The dangers arising from too great a degree of stability were well illustrated in the case of two Spanish ships of war. That nation, by the application of scientific principles to naval architecture, had reached a degree of perfection which the French and English despaired of. As an instance of this, we may cite the fact, that when the French had almost abandoned the attempt to build three-decked ships, *and those constructed* by the English were so infe-

rior in their qualities as sea-boats, that the model of one (the Victory) which had been approved in service was preserved by continual rebuilding, the Spaniards were successful in building a vessel of four decks. Among the vessels built at this period in Spain were two of two decks. These never left the port without being compelled to return dismasted by the first gale of wind. This defect was remedied by converting them into vessels of three decks, by which their excess of stability was diminished, and, with it, the violence of the rolling motion.

In our steamboats, the engines and boilers are often placed on the wheel-guards, while the English have taken great pains to place these heavy weights as low and as near as possible to the plane of the keel. It may be doubted whether the practice of the Americans in this respect is not superior, even in sea-going vessels, inasmuch as the rapidity of the rolling motion is increased in steam-vessels by the lessening of the length of the masts and of the quantity of sail, and therefore requires to be counteracted by raising the weight carried in the hull of the vessel. At all events, it must be admitted, that if the American practice is erroneous in diminishing the stability, the English method is not less so in increasing the violence of the rolling motion, and the most advantageous position of these weights will probably be found between these two extremes.

240. Vessels are also liable to an oscillating motion in a direction from stem to stern, which is called pitching. By this the vessel may be rendered wet, the masts and rigging may be strained or carried away, and there are even cases in which it has caused the vessel to founder. In consequence of the great proportion which the length bears to the breadth of the vessel, these oscillations are more influenced by the

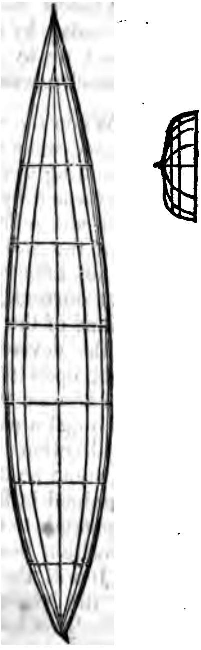
waves than by the winds. While danger arises in the act of rolling from too great a frequency in the oscillations, the danger of pitching is increased by the extent of the arc in which the motion is performed, and lessened by increasing the number of oscillations in a given time. In order to mitigate the violence of pitching, the weight in stowage ought therefore to be placed as near as possible to the midship section. In the building and rigging, all heavy masses near the bow and stern are therefore to be avoided. In conformity with this rule, the heavy figure-heads, quarter-galleries, and poops, with which ships were formerly encumbered rather than embellished, are now omitted.

241. So long as a vessel remains at rest, the pressure of the fluid acts upon it equally in all directions; but, as soon as it is set in motion from any cause, a resistance is opposed to its progress. In a given vessel, this resistance appears at first to follow the law which is usually stated as that of fluid resistance, namely, that of the square of the velocity. As the velocity increases, a new cause of resistance appears. This is owing to the fact that a wave is usually raised in front of the vessel, while the fluid does not close behind it, and thus the propelling force must be in part exerted to raise the vessel up an inclined plane. This cause of resistance is stated by Juan to follow the law of the fourth power of the velocity. By more recent investigations, it seems to have been proved, that when the wave moves in the fluid at the same rate with the vessel, this rather aids than opposes the motion. The velocity of this wave depends upon the magnitude and figure of the channel; we cannot, therefore, state any general rule by which it is governed.

The resistance to the progressive motion of a vessel *is greatest* when the prow is a vertical plane.

When a wedge is applied to such a surface, the resistance is, according to theory, diminished in the ratio of the square of the cosine. Hence the more acute the prow, the less will be the resistance. It has been attempted to investigate analytically the figure of the prow of least resistance, but as the law we have stated is not absolutely true, the investigation is of no practical value. The void space left behind the vessel is diminished by giving to the stern the shape of a wedge also, and the velocity given by a constant force will be greatest when the wedge of the stern is more acute than that of the bow.

Fig. 79.



A rectangle terminated by wedges is far from being the best form for the horizontal section of a vessel. The resistance may be lessened by giving to this section the figure of a continuous curve, from stem to stern. At the load-water-line, it would appear from experiment, the main breadth should be at a distance of three eighths from the bow, and five eighths of the length from the stern; and the curves in this plane may be convex in both directions. Below the surface of the water the curves should continue to be convex towards the bow, but should gradually become concave towards the stern. Water-lines of this character are represented in *Fig. 79.*

In the vessels recently built in the port of New-York, models founded on this principle have been adopted. The floor is nearly level from stem to stern, and the midship section is as nearly rectangular as is consistent with the proper connexion of the timbers which compose the frame. These vessels, therefore, draw much less water than those of the old construction, but, to the surprise of nautical men, they have also been found better sailers.

242. Vessels may be propelled by the wind acting upon sails; by the force of men acting upon oars or paddles; or by the steam-engine, acting usually upon a wheel resembling the undershot water-wheel.

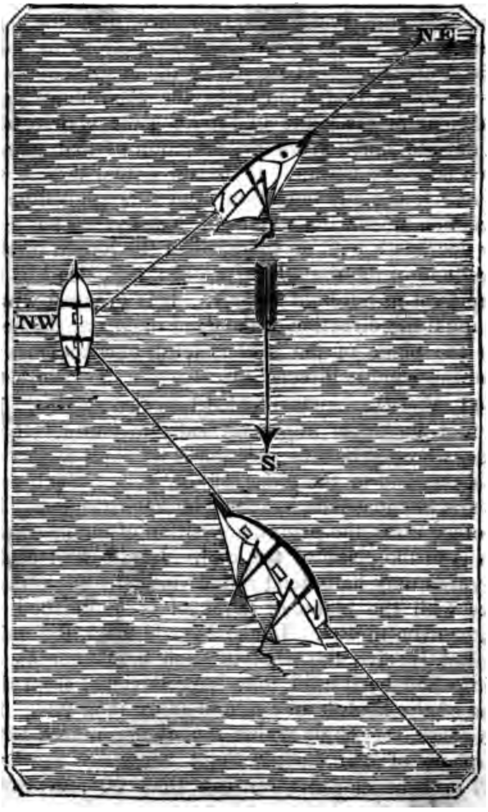
243. When the wind acts upon sails, it is thrown off in consequence of its elasticity, and the direction of the resulting force is not that of the wind, but at an angle formed by a line bisecting the directions of the direct and reflected current of air. Were the surface of the sail a plane, and were the reflected current not affected by the succeeding portions of the direct current, this line would be perpendicular to the plane of the sail. It is impossible to take into account the deviation which is due to the action of the direct upon the reflected current, and we shall therefore assume that the direction in which the wind tends to impel a sail is perpendicular to its surface. In this direction, the vessel, if its water-lines were circles, would be caused to move, provided it could be maintained in that course. But the force of the wind also tends to make the sail revolve, until it come into a position perpendicular to the direction of the wind. It will therefore require some apparatus to prevent the vessel from obeying this tendency to revolve. The horizontal section of vessels at the *level of the water* is far from being circular. The

proportion of the length to the breadth is rarely less than 3 : 1, and usually greater. The bow forms an acute wedge, the direct progress of which is but little resisted, while the resistance to a lateral motion is little less than would be sustained by a plane surface. It happens, therefore, from the tendency of the sail to move perpendicular to its own surface, and the great excess of the resistance to a lateral motion, that even when the wind blows perpendicular to the plane of the keel, the course will not deviate much from the direction of that plane, which is hence assumed to be the actual course of the vessel, and any deviation from it is applied as a correction under the name of leeway. The leeway decreases with an increase in the length of the vessel and of the draught of water; it is also less in sharp than in full-built vessels. It is greatest when the angle the direction of the wind makes at the bow with the plane of the keel is least, and becomes 0 when the wind is directly aft.

244. Vessels may be divided into two classes. In the first, the most important sails are attached to yards, whose primitive position is at right angles to the masts and to the plane of the keel. Such vessels are, in consequence, said to be square rigged. In the other class, the primitive position of the principal sails is in the plane of the keel. In the first class, the yards may be braced round until the angle they make with the plane of the keel is diminished to 45°, or even to 40°. In the second class, the sails will not receive the wind in such a manner as to be impelled by it until they have deviated from the plane of the keel to an angle of more than 20°. In both cases, the angle which the course makes with the plane of the keel, without allowance for leeway, may be considerably less than 90°, and may

be taken in many fore-and-aft rigged vessels as even less than 45°. Whenever this angle is less than 90°, the vessel, in its oblique course, approaches

Fig. 80.



towards the point whence the wind appears to blow, and is said to beat or ply to windward. It may thus happen that, by pursuing two oblique courses in succession, a vessel may reach a point whence the wind appeared to blow when it set out.

In Fig. 80, the wind is represented as blowing from the north. The lower of the two fore-and-aft rigged vessels may therefore pursue a course due northwest, and, on coming to the point marked N W, may tack, and thence pursue the course on which the upper vessel is represented as proceeding, to the northeast.

In plying to windward, a part of the velocity of the vessel, if resolved into two components, is in direct opposition to the velocity of the wind, and the velocity with which the wind strikes the sails is the sum of the two. Hence the action of the wind in oblique courses is increased, and the velocity of the vessel with it. With the last velocity the resistances increase also, and in a higher ratio; hence there is a limit to the increase; but the singular results are thus reached, that a vessel of good construction shall ply to windward on two courses to a given point, in less time than it can return before the wind, and that the velocity of the vessel in beating may be greater than that of the wind itself.

Both of these facts were observed by Juan on the ferry between Cadiz and Matagorda.

When before the wind, on the other hand, the velocity through the water can never equal that of the wind; but, as the course becomes more and more oblique, the velocity of a well-moulded vessel will increase up to a certain point, when it will again diminish. The position of maximum velocity in a square-rigged vessel of good figure, is usually that in which the direction of the wind is at right angles to the plane of the keel.

The method of plying to windward was, in all probability, unknown to the ancients, and was, as is believed, introduced in Europe by the navigators of Amalfi, in Italy. To this day it does not seem to be known to the people of China and Japan. It is a remarkable fact, that while these comparatively civilized nations are deficient in this point of seamanship, a rude people, the natives of the Ladrone Islands, in their neighbourhood, were found in possession of the most perfect vessel which has ever been contrived for this purpose, and which, from its properties of sailing, has been called the flying proa.

The body of a flying proa resembles that of a vessel which has been cut in two along the plane of the keel, and having this plane planked up. It thus presents a surface which is only resisted in its progressive motion half as much as that of a vessel of the usual form, and having an equal midship section. As it could not remain upright with a figure of this kind, there is a long outrigger formed of spars, which projects from the curved side, and is terminated in a solid piece of wood fashioned into the form of a vessel. When the vessel tends to incline in this direction, the buoyancy of the outrigger opposes the inclination; and, should the wind tend to incline it in the opposite direction, the weight of the outrigger produces a similar effect. The proa, therefore, floats with little variation from an erect position. The plane surface is, on an oblique course, turned towards the wind, and, in connexion with the outrigger, opposes such a resistance to leeway as to render it almost insensible. The sails are triangular in figure, and will draw at a less angle with the wind than those of any other vessel. This advantage is partly gained by an arrangement similar to that of the sails of the Chinese. This consists in a number of slender rods

stretched along the sail in a horizontal direction, by which the sail is prevented from swelling or bellying except in the vertical direction.

In connexion with this last circumstance, it may be stated that the sails of European vessels were formerly so cut as to permit them to bag or belly considerably. A better practice is now in use in this country, where they are cut to lie as flat as possible; and, in order to ensure this, in fore-and-aft rigged vessels, the sail is not merely fixed at its two lower corners as formerly, but is tied down to the boom at short intervals.

The periauga used in the waters of New-York and New-Jersey has also excellent qualities in oblique courses. Its name would seem to import that it is in part borrowed from the pirogue of the Indians. But the great tendency which its canoe shape and small draught of water would give it to leeway, is counteracted by lee-boards, which are borrowed from the Dutch schuyt. For these a sliding keel or centre-board is now usually substituted, and the shape of the hull approaches more nearly to that of other vessels.

The pilot-boat schooner of the United States, however, appears to combine a greater number of good qualities, of which its capacity of lying near the wind is but one, than any other vessel.

245. The direction of a vessel on an oblique course is principally maintained by the trim of the sails. When these are so distributed that the several actions of the wind upon them are in equilibrio around the vertical axis of the vessel, there is no tendency to a change of course. Such a trim is, however, never practised, because it is possible that, in oblique courses, the action of the wind may become sufficient to upset the vessel. When a vessel is rig-

ged with square sails, security from this danger is best attained by turning the head of the vessel from the direction of the wind. In this case the vessel is said to *bear away*, and the sails ought to be so trimmed that there shall be a constant tendency to this change of course. In fore-and-aft rigged vessels, security from this danger is best attained by turning the head towards the wind, until the sails shake; they are then said to *luff*.

The tendency to bear away or to luff in these two cases requires to be counteracted. This is done by the action of the rudder. The rudder is a flat body of wood hung upon the stern-post. When a vessel is in motion, a current of equal velocity sets along both sides. If, now, the rudder be caused to change its primitive position in the plane of the keel, it interrupts the flow of the current on the side towards which it is inclined, and by this interruption causes the vessel to turn on its vertical axis towards the side on which the rudder is protruded. The rudder also serves to change the direction of the course of vessels. It would appear, from an analytic investigation, that if the surface of the vessel were a plane, the rudder would produce the greatest effect when it makes with that surface an angle 54° 44′. But, in consequence of the wedge-like shape of the stern, the most advantageous angle with the plane of the keel is found in practice to lie between 45° and 48°.

The figure of the water-lines towards the stern, which we have stated ought to be concave curves, is also advantageous to the action of the rudder. Vessels having such curves are said to be *clean* aft, and they always steer easily.

It will be obvious, from what has been said of the manner in which the rudder acts, that it has no effect when the vessel is not moving through the water.

246. Vessels in plying to windward may change their course in two different ways, called tacking, and veering or wearing. In tacking, the head of the vessel is thrown towards the wind by the action of the rudder, until the direction of the plane of the keel is the same as that of the wind. The sails shake in this position, in fore-and-aft rigged vessels, and are taken aback, in square-rigged vessels. By these means the velocity of the vessel is lessened, and, should it be altogether destroyed, the manœuvre cannot be performed. But if sufficient velocity is left to cause the vessel to obey the rudder, the action of the wind on the sails is caused to aid in the completion of the manœuvre. This is done by keeping the head-sails in the position in which they were before the tack commenced, while the sails abaft are either permitted to obey the impulse of the wind, or are trimmed, by bracing the yards around, to receive it from the opposite side. Finally, the head-sails are either permitted to obey the impulse of the wind, or braced round.

After the tack is performed, the vessel will be some time in regaining its previous velocity. During this time, the course of the vessel by the compass, or as observed from the shore, will be continually changing, although the apparent angle of the wind with the plane of the keel, as observed in the vessel, will remain unvaried. This is owing to the fact that the apparent direction of the wind is that of the resultant of its own velocity and that of the vessel. This circumstance is peculiarly worthy of notice, inasmuch as the observation of it led Bradley to his brilliant discovery of the cause of the aberration of the fixed stars, and thus to a direct proof of the revolution of the earth around the sun in an annual orbit.

Vessels rigged fore-and-aft are more certain to perform the operation of tacking than those which are square-rigged; fast-sailing and sharp-built vessels do it better than those which are full-built. The operation is impeded by waves, and hence ships seldom resort to it at sea, and more particularly in naval actions, because a failure to complete it, or, as it is called, missing stays, leaves the vessel for a time helpless.

247. The manœuvre of veering is performed by turning the head of the vessel from the wind, trimming the sails to correspond with the revolution until the plane of the keel makes the same angle with the wind as before, but on the opposite side. In the act of tacking, the sails shake or are taken aback; in the act of veering, the sails are kept full, and the vessel is for an instant exactly before the wind. The act of veering is performed with greater facility by square-rigged vessels than by fore-and-aft, and by short vessels than by long ones.

The flying proa, of which we have spoken, does not change her course by either of these methods, but does it partly by a portion of the manœuvre of veering and partly by changing the position of the sails, so that the part of the proa which was before the stern becomes the bow. This method is practicable in this case, because both ends are exactly alike, and the mast, which is stepped upon the outrigger, is equidistant from them.

248. Vessels, generally speaking, sail best the more nearly they retain a vertical position. Indeed, this is always the case, except when, in giving them stability, the violence of rolling is increased. Hence, in increasing the area of the sails in a given vessel, it is better to do it by increasing the length of the yards rather than that of the masts, for the action of

a wind of given force to propel the vessel depends upon the area of the sails, while that which tends to overturn the vessel depends on the distance at which the disturbing force acts, as well as upon this area.

249. The masts of vessels ought in most cases to be vertical, leaning neither towards the bow nor towards the stern. In very sharp vessels they may lean towards the stern, for in that case a part of the force will be exerted to prevent the vessel from burying itself too deep in the act of pitching. When the wind acts from abaft, its action will generally be in part exerted to depress the bow. Hence vessels are usually so constructed and loaded that the draught of water shall be less at the bow than at the stern, and nearly all vessels sail best when this is the case.

250. When vessels are propelled by steam, the apparatus which is now used, to the exclusion of all others, is a paddle-wheel, resembling, in its general form and construction, the undershot water-wheel. From this it must, however, differ in the number of its floats; for while in the undershot wheel the number of floats should be such that four may be immersed at one time, no more than two should be immersed in the paddle-wheel. The reason of this difference is, that in the undershot wheel the action of the water will be increased by obstructing its flow past the wheel, while in the paddle-wheel it is advantageous that the wheel should strike against water which has not been disturbed, or disturbed as little as possible, by the preceding paddles.

Paddles placed at such distances from each other on a wheel meet with a resistance from the water which is continually varying. The motion of the wheel would thus be rendered even more irregular than it would under the varying action of the steam

on the piston of the engine. The action of the wheel itself as a fly does not compensate these irregularities. In the earlier and more slowly-moving steam-boats, it was therefore found expedient to make use of a fly-wheel, driven with a velocity greater than that of the paddle-wheel. In more rapid motions this was less necessary; and a motion has finally been obtained, subject to no greater inequalities than the inertia of the wheel itself is capable of controlling. This is done by the wheel of Stevens, whose construction may be understood by supposing a common paddle-wheel to be sawn into three equal portions, divided by two planes perpendicular to the axis, and that two of these portions are moved backward until the arc intercepted between two of the original paddles is divided into three equal parts. The number of impulses given by the wheel is therefore tripled, and each has only a third of the original intensity. The paddles do not follow in each other's wake, and hence each enters into water which has been but little disturbed by the preceding paddles. This method appears to possess advantages over the method used by the English, in which the several paddles are each divided into three parts, by cutting them in a direction parallel to the face of the wheel.

251. It has been attempted to cause the paddle to enter the water in a vertical position, and continue in such a position during the whole time of its immersion. This attempt has been founded on the impression that the action of the paddle was most powerful under such circumstances. Actual observation has shown that this impression is incorrect; and Barlow has demonstrated conclusively that the maximum of the effect of a common paddle-wheel does not occur when the paddle is vertical.

The theory of the action of paddle-wheels has not

been satisfactorily solved by analysts. This is partly owing to the imperfection we have remarked in the theory of the engine itself, which has not hitherto had any regard to the difference of pressure of the steam upon a piston when at rest and when in motion, and partly to the want of a satisfactory analytic expression for the action of the wheel on the water. The theory has therefore led to a conclusion which is contradicted by all the facts, and in the hands of Tredgold to one which is manifestly absurd.

The first of these conclusions is, that the relation between the velocity of the vessel and that of the wheel is a constant quantity, or may be expressed by the formula

$$\frac{V}{v}=m.$$

The fact, obtained by a comparison of the rates of many vessels, and of the same vessel moved with powers varying in the ratio of 2 : 1, is, that the difference between these two velocities, or the relative velocity of the circumference of the wheel is, in wheels of similar form, a constant quantity. This fact may be represented by the expression

$$V-v=n.$$

The absurdity into which Tredgold has been led is the statement that the velocity of a given vessel through the water will be different according as it moves with or against the current. Now if we consider a vessel to be in the first place abandoned to the stream, it will speedily acquire the velocity of the current, and be at rest relatively. If, now, the engine be set in motion, the velocity in relation to the water will be the same in any direction whatever, and the same result will be reached, even if the ves-

sel be set in motion on leaving a fixed fastening to the shore, by which a current is moving. The velocity, which we have stated as constant in similar wheels, varies in different wheels, according to the depth they are immersed in the water, and the number of paddles which occur on their circumference, from 6.2 feet to 6.8 feet per second.

252. In the usual theory it is assumed that the resistance is, in all cases, proportioned to the squares of the velocities. Hence the power of the engine ought to vary with the cube of the velocity, and the expenditure of fuel, in passing through a given distance, with the squares of the velocities. The experience of American engineers seems to prove that this assumption is not true at the higher velocities. They have found that every increase in the rate of the revolution of the wheel, has been attended with an increase, not proportioned to it, but absolutely equal, in the velocity of the vessel. If this be true: the measure of the resistance to a given vessel is constant, like friction; the expenditure of fuel in a given time should be as the velocity, and, in passing through a given distance, constant. The nominal power of the engines should increase simply with the velocity, and the increase in the action of the prime mover be applied to increase velocity only. We are aware that these principles appear startling to European engineers and mathematicians, and have already undergone their censure for having stated them. Actual experiment can alone decide between us.

In the mean time, we may cite European experience in relation to the motion of boats on a canal, which in some measure bear out our conclusions.

In experiments made on the Paisley Canal, two horses drew a passage-boat, weighing, with her load, 3½ tons, at the rate of 10.383 miles per hour, and

exerted a force in draught, measured by the dynamometer, of 285.15 lbs. Now, taking for a basis of calculation that a horse, exerting a force in draught of 186⅔ lbs. is capable of drawing a weight of 30 tons with a velocity of 2½ miles per hour, the force necessary to draw 8½ tons at the above velocity, if the resistance increased with the square of the velocity, ought to have been 746.6 lbs. Up to this limit, however, the resistance increases in a ratio greater than that of the simple velocity; for, calculated on that hypothesis, the measure should have been no more than 190 lbs.

It is obvious that much remains to be done, not only in the theory of the application of steam to navigation, but in the investigation of the experimental laws which serve as its basis; and it is unfortunate that no experiments have yet been made at velocities greater than the least which are now ever given to steamboats.*

* According to the theory which is now usually received:

(1.) The force required to move vessels of similar figures with equal velocities, varies with the squares of their homologous dimensions. This proposition alone is unquestionably true.

(2.) The relative velocity of the wheels ought to be increased with the diminution of the relation of their areas to that of the midship section of the vessel. This cannot be effected in practice, because this relative velocity is constant.

(3.) The power of the engine must vary with the area of the midship section, with the cube of the velocity, and with the square root of the relation between the midship section and the paddles, augmented by unity.

(4.) The velocity is directly proportioned to the cube root of the power of the engine, and inversely to the cube root of the area of the midship section.

(5.) From these laws an expression has been deduced for the velocity to be attained in the average of vessels by a given power of engine. This is

$$V=2\sqrt[3]{\frac{F}{b\,d}};$$

F *being* the number of horse powers, *b* the breadth, and *d* the *draught of water.*

253. In the construction of steam-vessels, which are not intended to navigate the ocean, the only point which is of importance in their models is to give them the figure of least resistance; and the most important part of this resistance is the wave which tends to be raised in front of the vessel, taken along with the depression which is caused in the wake. Our builders have sought this figure by continual experiment and observation, adapting false prows and sterns to the vessels, and noting the effects they produced. The practice derived from this course of experiment is so successful, that there are vessels in our waters which throw up no sensible wave, and leave no depression behind them. This was the case with the New-York, which was recently destroyed by fire. In sea-going vessels, this advantage must probably be sacrificed, in order to obtain others which are of more moment. These are strength, stability, and security from the injuries produced by pitching and rolling under the action of the waves. As yet, at least, the qualities of speed and safety at sea have not been found compatible.

Supposing that it were true that there is a constant relation of the velocities of the vessel and the wheel, the maximum velocity of a steam-vessel, if that stated for the paddle be the limit, would be about 12 nautical miles per hour. Our American steam-vessels, however, have considerably exceeded this theoretic maximum.

254. An engine, of the structure which has been described, requires to be modified before it can be used in navigation. The cold-water cistern is dispensed with as lessening the buoyancy of the vessel. In lieu of this, the condenser has been increased in volume four fold. The water of condensation is introduced into the condenser by means of a pipe pass-

ing through the bottom of the vessel, in which the water rises as high as the water without. The surplus of water from the hot-water cistern is discharged through a similar pipe. The boiler can no longer be set in masonry; hence the furnace is formed by the metallic surfaces of the boiler, and the flues pass through it.

In American steamboat engines, the connecting-rod has been lengthened, and thus acts with less obliquity; the stroke of the piston has been lengthened also, and thus the crank is made to act upon the wheel at a more favourable point; for it is obvious, that it is only when it acts at a distance from the axis of the wheel, which is equal to that of the centre of pressure on the paddle, that the two forces exactly counterbalance each other, and that none of the force of the prime mover is wasted upon the axle of the wheel. It would be impracticable to make the crank of sufficient length to attain this most advantageous position, but the more nearly it approaches to it the better.

In the English engines, from a desire to keep the weight as low as possible, the comparative length of the stroke has been lessened. The crank is therefore applied to a point which is less favourable. In the American method, too, it has been possible to give a greater mean velocity of the piston, because the dead points recur less frequently.

In order to secure this last advantage, the area of the steam-pipes and of the valves has been much increased; thus the velocity of the pistons of the American boat engines has been raised, from the old limit of little more than 200 feet per minute, to nearly 600 feet.

255. Paddle-wheels cannot be used upon canals, in consequence of the great agitation they produ[illegible]

in the water, and consequent injury to the banks. It has been proposed in France, by Tourasse, to apply steam to vessels upon canals by means of a chain extending along the bottom from lock to lock. This is lifted, and wound around a barrel placed on the axle of the crank. By the revolution of the axle, the chain is drawn in from the bow of the boat, and discharged in the opposite direction. In this way, the whole force of the steam-engine will be employed in the draught. The great objection to the method lies in the original cost of the chains. In passing short distances, as upon a ferry, this objection does not apply, and this plan has been recently successfully used upon a ferry in England.

We have recently seen a great improvement on this method, by Mr. Leavenworth, of New-York. He has ascertained, that the mere friction of a chain on the bottom of a canal is sufficient to propel a boat along it. He therefore makes use of an endless chain, extending from near the bows almost to the stern of the boat. This is set in motion by an axle moved by the steam-engine, and while one branch of the chain is carried along with the boat, the other drops on the bottom of the canal. This apparatus has been used with success upon the Morris Canal.

XI.

MACHINES USED IN MANUFACTURES.

256. MACHINES used in manufactures may be propelled by any of the great natural agents. The force of men, of animals, and of the wind, have been all, and are still occasionally employed; but water acting upon wheels, and the steam-engine, are better suited to all cases in which regularity and permanency of action are required. Up to the present time, the force of water is regarded in the most favourable light in the United States, but it may be questioned whether this preference be well founded. In those districts of our country where there is at present a surplus population applicable to manufacturing purposes, fuel is dear, and water-power is abundant; it is therefore considered as the most economic. But water is, at best, an uncertain power; the machinery may be prevented from working, not only in seasons of drought, but by the fulness of the streams; the dams and races by which the power is supplied are liable to injury and destruction by floods. Water-power must also be sought, and the manufacturer must leave all other considerations out of view in choosing a site for his establishment. We have seen calculations founded on actual facts, by which it has been shown that, taking all things into account, the actual cost of cotton goods manufactured by steam in the city of New-York, is less than that of similar articles manufactured in Patterson by water-power.

257. The velocity with which the fly of a steam-

engine or an overshot wheel revolves, in order to do the greatest quantity of work, may be considered as fixed. The velocities with which different descriptions of work are performed are each fixed, but are never the same, either in their direction or their rate, as those best adapted to the favourable action of the prime mover. It therefore becomes necessary to change the motion of the working point of the machine in its direction and intensity, for the purpose of performing the desired operation in a proper manner. These changes are principally performed by combinations of the wheel and axle, in its several modifications.

258. One wheel may turn another, or a wheel may turn an axle, by the direct friction of their respective circumferences. There are some cases in which the cylindrical surface of one wheel is thus made to turn another, but they are rare. The difficulty of using this method consists in the risk of sliding, and this can only be obviated by introducing a degree of friction which would render a combination of this sort inefficient. Nor would even a great friction answer the purpose, unless the velocity of the wheels and their mutual pressure were constant; but when, as is most frequently the case, the moving power or the resistance acts with variable intensity, it would be impossible to avoid the sliding.

259. The second mode in which wheels and axles may be combined with each other, is through the intervention of bands, composed of ropes, straps, or chains. These are also liable to slide; but this tendency is not always disadvantageous, although always attended with a loss of moving power, for the sliding of the band may prevent any risk of fracture in the parts of the machine or of the engine,

when the resistance is liable to sudden changes in its intensity.

The use of bands is principally confined to the case where the motion is to be transmitted to a distance. When ropes are employed, a groove must be cut in the circumference of the wheels, as in the pulley, and they may be made to change the plane in which the motion is performed.

When bands are employed, the surface of the wheels should be slightly curved. Flat chains should only be employed when the tension to which they are subjected is small, and the friction is not regarded. In other cases, chains formed like those of a watch, or made in links of the usual description, are caught upon teeth placed on the circumference of the wheels. The chain must be so long that its returning branch shall be slack.

The tension of bands often requires to be maintained by some extrinsic action, for it would not do to draw them too tight, in consequence of the great increase of friction which would be thus caused. The best mode of giving the proper degree of tension is by allowing a heavy wheel to rest on the bands, the axle of which is connected by a radius bar with a firm support. When thus loaded, the same band may be shifted from one axle to another of different diameter, while it is driven by a wheel of constant diameter, and different velocities may thus be given to the common axis of the several axles.

One of the most difficult cases in the use of bands to connect wheels and axles, is that in which it was wished to turn the potter's wheel by machinery, propelled by water or steam, instead of using human labour. So difficult was this considered, that, after it had for many years been attempted in vain, it was

almost abandoned as impracticable. Finally, the desired effect was obtained in the simplest possible manner; the band was passed over two cones, whose points or vertices were turned in opposite directions. Thus, when the band was passed over the middle of the cones, the velocities of both were equal, while, by moving it towards one or the other end, every desired variety in the rate of the motions could be obtained.

260. The third mode in which wheels and axles are combined, is by cutting their circumferences into teeth which catch into each other. The principles on which these toothed wheels and axles act, are a part of the theory of mechanics, and for them we refer to our Treatise on that subject.* It is there stated that there are two principal modifications of toothed wheels and axles, known under the names of the wheel and trundle, and the wheel and pinion. In the case of the wheel and trundle, a motion may be taken off at right angles by making the teeth of the wheel at right angles to its surface; these will adapt themselves to the staves of a trundle whose axis is also at right angles to that of the wheel. Motions of small obliquity may be taken off by means of the universal joint of Hook. To construct this, the axle of the wheel is forked in the form of a stirrup-iron at its extremity; another axle, lying in the desired direction, has its extremity of the same figure; the two axles are united by a cross, the ends of whose arms are turned, and thus formed into gudgeons, which rest in circular holes in the forked branches of the two axles.

When a trundle is applied to turn a wheel, it begins to act before the touching surfaces reach the

* Treatise on Mechanics, book iii., chap.

line which joins the centres, the friction is thus rendered great and the motion harsh. Even when the wheel turns the trundle, the combination is attended with inconvenience, from the harshness of the motion, and the great wear to which the staves of the trundle are subjected. To remedy this, the staves are usually made of iron, and the teeth of the wheel of wood; but the latter material is so soft that the inequality of wear is thus thrown upon it. The wheel and trundle is, however, so cheap and simple in its construction, that it is not wholly abandoned.

261. In the use of the wheel and pinion, motion may be taken off at right angles, by cutting the teeth of the wheel into the envelope of a hollow cylinder. This method has been described in speaking of the construction of the watch, under the name of the contrate wheel. In heavier machinery, motion at any desired angle may be taken off by cutting the teeth of the wheels or pinions which act upon each other upon the surfaces of two cones, whose vertices meet in the same point, and whose axes make with each other the required angle of obliquity.*

* In the construction of wheels and pinions it is necessary:

(1.) That the number of their respective teeth shall be in the inverse ratio of their respective angular velocities.

(2.) That, if two circles be drawn concentric with the wheels, and tangent to each other, whose radii are in the inverse ratio of their respective angular velocities, the arcs intercepted between the middle points of the consecutive teeth on these two circles shall be equal to each other; that is to say, not only shall such circumference be divided into parts exactly equal, but the parts on the two separate circles shall also be equal to each other; these circles are called the pitch-lines of the wheels.

(3.) The curved surfaces of the teeth must be so constructed that the uniform velocity of the driving wheel shall be communicated to the other, during the whole time of the contact of any two of their respective teeth.

For this purpose it is necessary so to arrange the thickness, the projection, and the intervening spaces of the teeth, that a given

tooth shall begin to act at the instant when that which precedes it is ceasing to touch the corresponding tooth on the other wheel.

It is, moreover, important that no teeth shall begin to act upon each other until their surfaces are respectively in the line which joins the two centres. In this case the friction is less, and the risk to the wheels from fracture is lessened also. The opposite surfaces of a given tooth are to be exactly alike, in order to provide for the reversal of the motion.

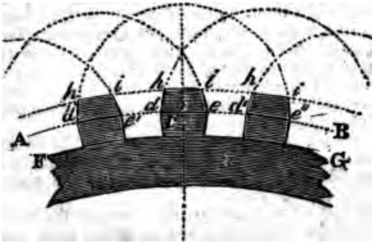
The least projection of the teeth beyond the pitch-lines of the wheels, must be such that one tooth shall arrive in the line which joins the centres of the circles at the instant the tooth which precedes it ceases to act; and the depth of the cavities below the pitch-line, must be such as will admit the free motion of the teeth of the other wheel.

The thickness and size of the teeth will depend upon the relation between the strength of the material of which they are composed and the strain to which they are subjected; and there must be a sufficient space between them not only to admit the teeth of the other wheel, but to allow a certain degree of play, to compensate for any imperfection in material or workmanship. This play, even in good workmanship, amounts to 1-10th or 1-12th of the thickness of the tooth, and ought generally to be more.

The teeth are bounded on each side by radii of the pitch-line reaching as far as the circumference of that circle from the bottom of the cavity, and the cavity terminates in an arc of a circle concentric with the pitch-line. From the pitch-line outward the proper figure is a portion of an epicycloid, described upon the pitch-line by the revolution of a circle whose diameter is half the pitch of the other wheel. These cycloidal arcs on the opposite sides of the tooth, should be cut off by a plane surface, at such a distance from the pitch-line as will prevent the tooth from continuing to act after that which precedes it reaches the line of the centres.

In practice, epicycloidal curves are difficult to construct; they are therefore replaced by circular arcs. The usual mode of construction may be understood from fig. 81.

Fig. 81.



262. In giving strength to the teeth of a wheel, it is better to increase the thickness of the wheel, and thus the length of the teeth, than the thickness of the teeth themselves. It is also better to make the wheels of large diameter, as thus the power acts upon a longer lever to overcome the friction. In this way also the number of teeth is increased, while the relation of those on the two wheels remains the same, and a more equable action is produced. In a pinion which has no more than eight teeth, each tooth begins to act before it reaches the line of the centres, and cannot be disengaged as soon as the following tooth begins to act. A pinion of ten teeth will not have the proper qualities if driven by a wheel of less than 72 teeth; but in all higher numbers there is no difficulty. Pinions of less than six teeth should never be used.

263. The principle on which the action of wheels and pinions rests, is as follows:* *The power is to the resistance as the continued product of the number of teeth on all the pinions is to the continued product of the teeth of all the wheels.* A train of pinions driving wheels is therefore a powerful means of increasing the intensity of a force, while, if its action

A C B is the pitch-line of the wheel, on which, after dividing it into as many equal parts as it is intended to form teeth, the half breadth of each tooth is set off on each side from the points of division, as from C to *d* and *e*. From the points *d* and *e* radii are drawn until they meet the circle F G, by which the cavities between the teeth are bounded. The curved faces of the teeth are formed by describing circles around the dividing points of the circle, as around C, as centres, with radii equal to the distance from such point to the opposite face of the contiguous tooth. This radius is equal to the cord of 1¼ of the divisions into which the pitch-line has been divided. The points formed by the intersecting arcs of these circles are then cut off by lines, *h-i*, parallel to the tangents of the pitch-line.

* See Treatise on Mechanics, book iii., chap. vi.

be reversed, and wheels are made to drive pinions, the velocity is increased in the same proportion. Of the latter case we have had instances in the structure of the clock and watch.

The direct problem of finding the relative times of revolution of two wheels or pinions belonging to the same train, is an easy and obvious application of the above principle. That of finding the proper number of wheels and pinions to be interposed, and the number of teeth upon each; is one of greater difficulty, and every complex case may admit of a variety of solutions. The mode of proceeding can be best illustrated by an example taken from one of the forms of clock.*

* Suppose it to be wished that a wheel which revolves in 2½ days shall give motion to another whose revolution shall be performed in 29½ days. The number of minutes in the first interval is 3600, and in the second 42,524; and any numbers having the same relation as these will represent the number of teeth which, if applied to two wheels, will answer the purpose. Both numbers being divisible by 4, 900 : 10,631 will express this relation. But so great a number of teeth as either of these cannot be constructed upon wheels, and the larger of the two is a prime number, which cannot be decomposed into factors, for the purpose of using these factors as the numbers of teeth on intermediate wheels. Instead of these numbers, then, two others are chosen, having nearly the same relation, namely, 703 : 8304. These numbers are each decomposed into two factors, thus: $703 = 19 \times 37$, $8304 = 48 \times 173$. If, then, a train of wheels be composed as follows: let a pinion of 19 teeth drive a wheel, B, of 48 teeth; place a pinion, *b*, on the same axle with B; give it 37 teeth, and let it drive a wheel of 173 teeth, the desired result will be obtained nearly. This is the case which is employed in clocks intended to show the phases of the moon, and it so happens that the relation 703 : 8304 is more near to that which the lunation bears to the solar day, than the one originally assumed.

Calculations of this sort are of most interest when it is intended, by means of clockwork, to represent the planetary motions. The best instance of this sort is the orrery constructed by Rittenhouse, a description of which may be seen in the life of that distinguished artist and astronomer, in Sparks's American Biography.

One of the best instances of a combination of wheels and pin-

ions to obtain an increase in the intensity of a force, is to be found in the machine for proving chain-cables.

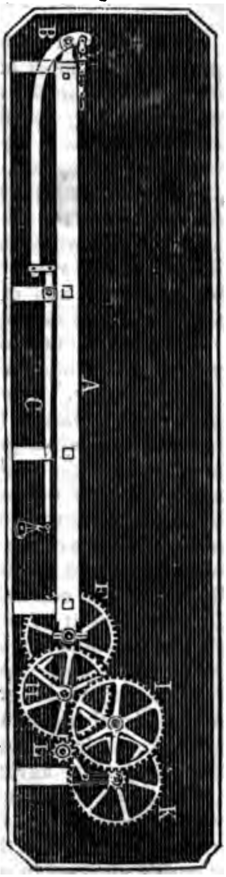
In this machine an axle of five inches in diameter, over which the chain is wound, is united to a wheel of two feet in diameter; this wheel, F, has 72 teeth, and is driven by a pinion of nine teeth; the latter is on the same axis with a wheel, H, of 97 teeth, driven by a pinion of eight teeth; the latter is on the same axis with a wheel, I, of 97 teeth, which is driven by a pinion of eight teeth; this pinion is on the same axis as the wheel K, of 97 teeth, which is driven by the pinion L, of eight teeth. The last pinion is two inches in diameter, and is turned by a winch, whose arm is 14 inches. Leaving out the odd tooth on the several wheels, inserted for the purpose of rendering the wear more equable, the relation of the power to the weight is

$$\frac{72}{9}\times\frac{96}{8}\times\frac{96}{8}\times\frac{96}{8}\times\frac{14}{5}=\frac{24}{3}\times\frac{24}{2}\times\frac{24}{2}\times\frac{24}{2}\times\frac{14}{5}=\frac{(24)^4 . 14}{2^3 . 3 . 5}=38,707.$$

If, then, a man, in turning a winch, exert a force of 30 pounds, and an allowance of one third be made for friction, he will act to stretch the cable submitted to the machine with a force equivalent to a weight of 36 tons.

The cable to be proved is stretched over a frame, A, and attached to the end of a curved lever, B; the longer arm of the lever B is acted upon by the shorter arm of a lever, C, from whose longer arm a weight is suspended.

Fig. 82.



Flouring Mills.

264. Mills are used for the purpose of grinding grain into the form of flour or meal, in which they are employed in the manufacture of bread. Originally moved by the force of men or animals, they are still in many countries driven by wind. All these prime movers, however, are so irregular in their action, that they are ill adapted to the purpose, for it is necessary that the work should be performed at a velocity which is confined within very narrow limits; at less velocities the grain is cut instead of being ground, and at greater, it is so much heated that it is liable to ferment in spite of any precaution.

The manufacture of wheaten flour was for many years among the most important objects of our national industry. It was almost the sole staple for export of the Middle States, and was carried on by merchant-millers of great capital, residing in the principal commercial cities. In the change which has taken place in the occupations of our countrymen, by which we have almost ceased to export breadstuff, in consequence of the great manufacturing population which has been created, the course of this trade has been altered; and although it has not ceased to be a favourite object of commercial enterprise, the position of the mills has been changed. The merchant-millers have been compelled to place themselves in the neighbourhood of the districts where an excess of breadstuff is produced, and many of the great establishments in the vicinity of the seaboard have gone to decay. The agriculturist has reaped this advantage, namely, that the prices of his products are now rather regulated by the cost of importing a similar article from abroad, than by the price at which it can *be safely shipped* to a foreign market.

During the time that wheaten flour was a great staple for export, the application of capital and ingenuity led to great improvements in the gristmill. Labour-saving machinery was introduced to such an extent, as to leave little or nothing for man to do, except to set it in action; and the mode of cleansing the grain and the meal from all impurities and products of inferior value, was brought to absolute perfection. The most perfect mills of this description in the world are probably those of Rochester, N. Y. Those on the Brandywine and at Richmond, Va., have also long been in high repute.

265. The usual grinding apparatus in a gristmill is composed of two circular stones. The lower one is fixed; the upper revolves on a vertical axis, which passes through the lower and is attached to the upper by a cross of iron, whose arms are sufficiently long to allow of a hole in the middle of the upper millstone, by which the grist is admitted to the space between the stones. The opposite surfaces of the two stones are divided into sectors, and these sectors are cut into groves, parallel to one of the radii which bound each sector. The cuts into the two millstones are precisely similar in number and position.

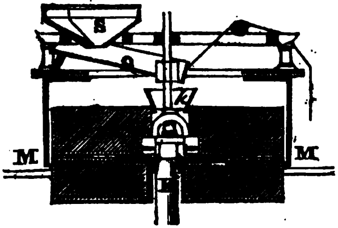
It will therefore be obvious, that when the upper millstone is set in its place, the directions of these grooves will cross each other. The surface of the lower stone is convex, that of the upper concave, and the convexity of the former has less height than the concavity of the latter has depth.

The grain, falling into the space between the millstones, is caught by the upper one in its revolution, and being partly crushed and partly cut by the projections of the grooves, is carried outward by the centrifugal force, until it passes between the circumfer-

ence of the upper millstone and the surface of the lower, into a box which surrounds both, whence the meal is discharged by a spout.

Fig. 83 represents a section of a pair of millstones, with their accessories.

Fig. 83.



D. Upper millstone.
R. Lower millstone.
K. Spindle which carries the upper millstone.
S. Hopper.
Q. Moveable hopper, called, from its shape, the shoe. This is shaken from side to side by four bars fastened to the top of the spindle.
k. Eye of the mill, an opening with a short funnel, through which the grain falls from the shoe.
M M. Case into which the meal is thrown from between the millstones by the centrifugal force derived from the rotary motion of the upper millstone.

266. It has been found that the force of a single man is capable of giving motion to an iron mill of 9 French inches in diameter, at the rate of 30 revolutions in a minute. The product is 20 metrical pounds per hour. A mill for two men has millstones 21 inches in diameter, and makes 80 revolutions per minute. The product is doubled.

In order to construct a mill for the power of a single horse or of seven men, it would be necessary, in making it move at the same rate, to give it a diameter of 31 inches; but it is made to revolve 120

times in a minute, and the surface is diminished to the diameter of 32 inches.

The French mills which are moved by water have a diameter of 72 inches, and make from 70 to 72 revolutions in a minute. These require the force of four horses. Many English mills have a diameter of four feet, and turn with a velocity of 120 revolutions in a minute. The force of three horses is sufficient to move them. The best English mills have a diameter of five feet, and revolve 90 times in a minute.

267. In the American flouring mills, the grain is raised from the vessels which carry it to the mills, or from a reservoir into which it is thrown from the sacks, by an apparatus called the elevator. This is composed of a number of small copper buckets attached to a leathern strap, and worked by the force which moves the mill, after the manner of a chain-pump. From the upper part of the elevator it is thrown by the motion of the buckets into a screen, by the action of which it is cleansed from the seeds of other substances and the smaller grains of the wheat itself. This screen is a polygonal prism enclosed in fine wires, which lies in a position slightly inclined, and is caused to revolve rapidly. The grain is thrown by the centrifugal force against the wires, and, after many revolutions, reaches the lower end of the screen, all the smaller seeds having escaped through the screen. The screen discharges the cleansed wheat into the granary, where it collects in a heap on the floor.

In the more perfect mills, the wheat is received from the elevators into a machine by which it is freed from smut. The smut machine is, in external figure and position, similar to the screen, but it is composed of one cylinder revolving within another.

The two cylinders are furnished with teeth or beaters, by which the smutty grains of the wheat are crushed; these are softer than the others, and therefore yield easily. Their fragments, with the smut they contain, are separated by the screen.

From the granary it is carried, as wanted, by an apparatus called a conductor. This is composed of a screw working in a trough. By this it is conveyed to a point whence it falls into the hopper, which is a pyramidal funnel. Beneath this is a moveable apparatus, which is touched by the millstone in its revolutions, and thus acted upon in such manner that the millstone receives exactly as much grain as will suffice for properly feeding it.

The meal, after being discharged from between the stones, is received in a horizontal trough, in which a skeleton screw, formed of leaves projected from a solid axis, works; by this it is carried forward to a reservoir, whence it is lifted, either by a similar screw working in an inclined position, or by an elevator, to the upper story of the mill. Falling upon the floor of this, it is spread out by an apparatus called the *hopper-boy* or cooler. This is composed of a sort of rake, consisting of two equal arms revolving on their centre. The teeth of the rake are inclined, and their number on the two arms is unequal, so that those on the one arm in revolving follow the spaces between the teeth of the other arm. The outer tooth of one of the arms catches the meal as it comes from the elevator, and drags it over the floor in the circumference of a circle. The outer tooth of the other arm moves the flour thus spread nearer to the centre of the apparatus, and so in succession until the meal reaches a hole near the centre. Through this hole it falls by its own weight into the bolting *machine*. The bolting machine has the same shape

as the screen, but is enclosed in a fine cloth, and the passage of the finely-ground flour through the cloth is aided by pieces of wood, called beaters, arranged at the edges of a prism similar, but somewhat larger than that which holds the bolting cloth. The latter, when loaded with the meal, is sufficiently flexible to be thrown against the beaters by the centrifugal force.

Within the bolting machine are arrangements by which the husk of the grain and the coarser parts are separated into portions of different value and fineness.

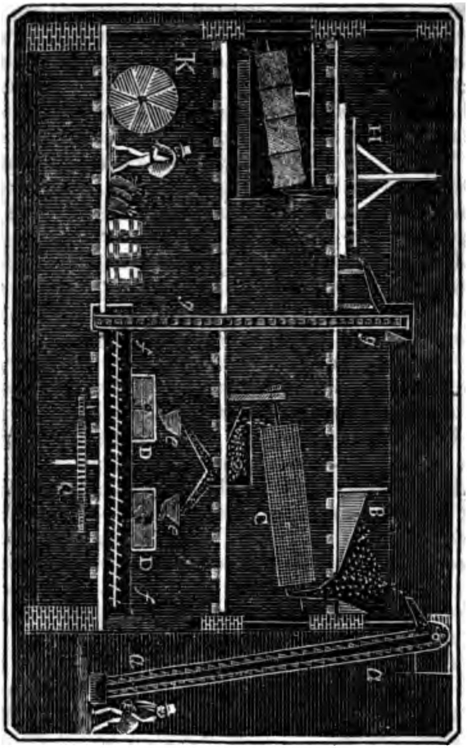
From the bolting machine the superfine flour is conveyed by machinery to a bin, in which it remains until it is to be packed, when, by merely opening a small gate in a spout, it is permitted to fall into the barrel. Into this it is rammed by machinery, and the workman has no more to do than to close the gate as soon as a barrel is filled, remove it, replace it by an empty one, and so on, until the whole of the grain is ground, or the mill is stopped.

In addition, there are in the best mills apparatus for weighing the wheat, and the flour in the barrels. The whole of the work, from the unlading of the vessels in which it is brought, to the package in barrels, is performed by machinery, and a single man with a boy are sufficient to perform the work of an extensive mill.

The distribution of the more important of these parts may be understood from Fig. 84, on page 268, in which the interior of a mill of four run of stones is represented.

a a. Elevators by which the grain is raised.
B. Granary.
C. Screen.
D D. Millstones; one of these, with its grooved face, is shown at K.
e e. Hoppers.
f f. Conducting screws by which the meal is conveyed to the elevator *g g*.
H. Cooler or Hopper-boy.
I. Bolting Machine.

Fig. 84.



268. Grist mills may be moved by any of the kinds of water-wheel which we have described, or by a steam-engine. It is estimated that for each pair of stones, with the labour-saving machinery, *the power of* four horses is sufficient. The hori-

zontal form of wheels has the merit of admitting of the utmost simplicity in their arrangement, for the spindle which carries the upper millstone may also be the axle of the horizontal wheel. It is, however, more difficult to regulate the velocity of these within the proper limits, and in many cases they would cause a great waste of the power. It is therefore better, in large manufacturing mills, to employ an undershot, overshot, or breast wheel, according to the circumstances of the case; and as both the plane in which they move, and the velocity best adapted to their most efficient action, are different from that of the millstone, the proper changes in the direction and rate of the motions are effected by means of bevelled and spur wheels.*

269. In mills driven by a water-wheel, the motion is usually taken off at right angles, and altered in velocity by a single combination, which was in the old mills composed of a cog-wheel and trundle, but which is now made up of a bevelled wheel and bevelled pinion. Using an undershot wheel having a diameter of 15 feet, which is a good proportion, Dr. Brewster gives the following table for a stone of five feet in diameter, making 90 revolutions per minute.

* As an example of such an arrangement, we shall take that of a mill moved by a steam-engine making 30 strokes per minute. On the axle of the crank is a bevelled wheel, having 84 teeth. This works into a second bevelled wheel, by which the horizontal motion is rendered vertical, and which has 72 teeth. The third wheel is mounted upon the same axle as the second, and has 36 teeth. The fourth wheel has 41 teeth, and the upper millstone is mounted on a spindle passing through its centre. The relation between the number of strokes of the engine and the number of revolutions of the millstone will be thus expressed:

$$\frac{84 \times 136}{72 \times 41} = 3.87.$$

The millstone will therefore make 116.1 revolutions per minute.

Velocity of Water.	Revolutions of wheel per minute.	Relation between the revolutions of the wheel and stones.	Teeth on the wheel.	Pinion.
7.62	4.16	21.63	130	6
10.77	4.62	15.31	92	6
13.26	7.20	12.50	100	8
15.24	8.32	10.81	97	9
17.04	9.28	9.70	97	10
18.67	8	8.83	97	11
20.15	8.64	8.19	90	11

The relations in the overshot and breast wheels, whose circumferences move with a constant velocity, can be calculated with great care. The following table is given by Brewster for the use of the condensing low-pressure engine in driving grist-mills.*

Bushels ground per hour.	Diameter of cylinder. Inches.	Bushels ground per hour.	Diameter of cylinder. Inches.
4	12.5	28	29.8
8	16.75	32	32
12	20.2	36	34.2
16	23.25	40	36
20	26.25	44	38
24	28.1	48	39.5

* As a farther illustration of this subject, we give a description of a mill at Rochester, N. Y. The water-wheels are three in number, each of which drives three run of stones, and is 18 feet in diameter. The buckets are 11 feet 3 inches in length in the clear. The head of water is 18 feet, and is usually admitted upon the wheel at the distance of three feet from its upright diameter. This (§ 38) we have seen to be a more advantageous mode than if the wheel were made small enough to let the water spout against its upper bucket. The gate through which the water passes is 3¼ inches high, and is usually drawn 2 inches.

Each wheel has on its axle a bevel-wheel 11 feet in diameter, and having 144 teeth. These wheels drive horizontal pinions having 36 teeth, on the same axle with which are spur-wheels 10 feet in diameter, having 144 cogs. These drive pinions of 25 teeth, which carry the millstones.

The millstones are 5 feet in diameter, and make 140 revolutions per minute, and each run of stones grinds from 8 to 10 bushels of wheat per hour. The usual product of the mill, having nine run of stones, is from 300 to 400 barrels of flour in 24 hours. But in a press of work, as much as 600 barrels have occasionally been manufactured.

To sift the flour there are four large bolting chests, each containing four reels 30 inches in diameter and 18 feet in length.

Saw-Mills.

270. Saw-mills have also constituted an important branch of American industry. These, as erected in most places, are of the simplest possible structure. There is but one saw, which is mounted in a frame, to which the appropriate oscillating motion is given by a small wheel, or rather axle furnished with four leaves. On this the water is admitted by an inclined spout reaching to the head of the fall. On the axle of this wheel is a crank connected with the frame by a rod. The log to be sawn is laid on a frame, which is pushed forward at each oscillation of the frame by a ratchet wheel.

This mode is only to be praised for its small cost and simplicity, but it is a very inefficient method of using the water, being driven by an undershot wheel of the worst structure. The saw-mills of greater power, which carry gangs of saws in sufficient number to cut a log at one operation into the greatest number of boards into which it can be divided, are driven by an overshot wheel, the motion of which

There are also four hopper-boys for cooling the meal before it is bolted; a bolting chest with a single reel for middlings, and a duster for rebolting the bran. The reels are 42 inches in diameter and 22 feet long.

The elevator raises the grain from boats to a height of 48 feet, and is of sufficient capacity to raise 1000 bushels in an hour and a half; and there are arrangements for weighing the grain as fast as it is elevated.

According to the ratio of the number of teeth on the wheels and pinions, the water-wheels make about six revolutions per minute, and the rate at which their circumference moves is about six feet per second.

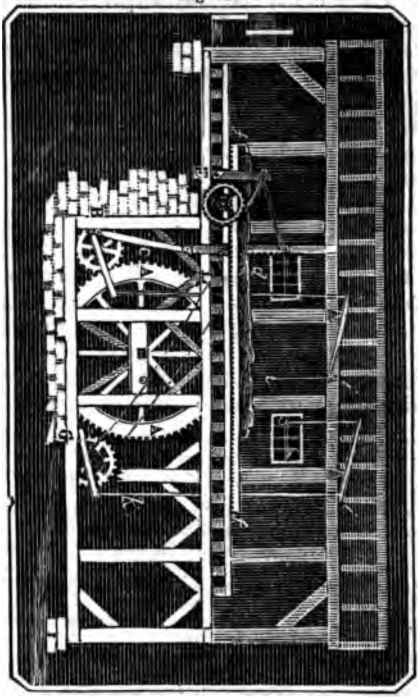
As the water is apt to fail in times of drought, a steam-engine of 80 horse power is attached, which can be geared to the upright shafts, driven by two of the wheels, and thus six run of stones may, if necessary, be driven by steam, while three are driven by the remaining water-wheel.

For cleaning the wheat there are three screens, two smut machines, and three fanning-mills.

is changed in velocity by a wheel and pinion, to the axle of the latter of which a crank is applied.

A saw-mill of this construction is represented in Fig. 85.

Fig. 85.



A A. Overshot water-wheel, on the circumference of which cogs are placed.

B. Pinion and crank, which, by means of the connecting rod *c*, gives motion to the frame *d*, which carries the saw.

E. Ratchet wheel, which derives its motion from the frame *d* in such manner as to be carried forward one tooth at each cut of the saw, and thus force up the moveable carriage *f f*, on which the log to be sawn is placed.
G. Pinion which can be thrown in and out of gear by the system of levers *i i k*. On the axle of this pinion is a band, which gives motion to a wheel L, by which the carriage *f f* is returned to its original position after the log has been sawn through.

Self-acting apparatus, by which the gate may be closed, the wheel which withdraws the carriage thrown into gear, and the log shifted the thickness of the scantling between each motion of the carriage, have been added to mills; the logs are also drawn up on an inclined plane by the machinery.

271. Instead of a straight saw oscillating in a frame, circular saws have been recently much employed. Some difficulties have been found in applying them to sawing heavy timber; but for sawing veneers, and all light work, they are to be preferred, in consequence of the greater rapidity with which they perform their work, the greater smoothness of the cuts they make, and a saving in power. In cutting veneers, the axle of the wheel has in some cases been made to rise and fall, thus combining the advantages of the oscillating and the circular motion.

One of the most complete and important combinations of circular saws, is that employed in Glasgow (Scotland) in the fabrication of barrels.

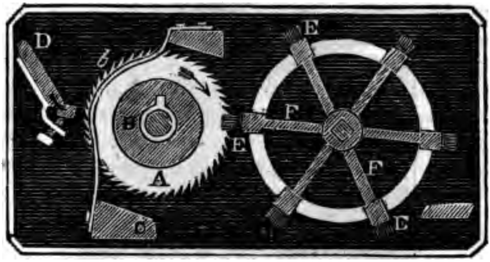
272. Planing machines may be considered with saw-mills. The work of planing wood is effected in these by knives placed in an oblique direction on the circumference of a cylinder. A machine for tonguing and grooving plank for flooring has been constructed on the same principles. The grooves are cut by a thin cylinder, having cutting teeth on its circumference. The tongue is formed by two

such cylinders revolving parallel to each other on the same axle. The planks are reduced to the proper width by passing them between two circular saws. These circular saws, the planing knives, and the tonguing and grooving instruments, are so combined that the whole process is performed at one operation, and a rough plank introduced at one end of the machine, comes out finished and fit for laying in a floor at the other.

Cotton Spinning.

273. Of all American products cotton is now the most important, from its value as an export, and the great extent to which its domestic consumption has been carried. This article is of two different species, the long and the short staple. The former is easily cleansed of its seed by a simple apparatus composed of toothed rollers. The short staple cotton is cleansed with greater difficulty, but the process is now effectually performed by an ingenious instrument, invented by Whitney, and called the saw-gin. The essential part of this apparatus is an axle, B, to which are adapted a number of fine circular saws. A section of this axle and one of the saws is represented at A, in Fig. 86. The bolls of cotton, with the seed attached to it, being thrown into the hopper D, the points of the saws, at *b*, in their revolution, tear the cotton from the seeds, and the latter, being left free, drop through an aperture in the bottom of the hopper, which is regulated by a screw so as just to permit them to pass. The cotton, carried forward by the teeth of the saws, is removed from them by brushes, E E, which revolve on the circumference of the wheel F F; it is thus thrown upon the inclined plane C, whence it descends to a receptacle beneath the machine. Nothing can well be

Fig. 86.

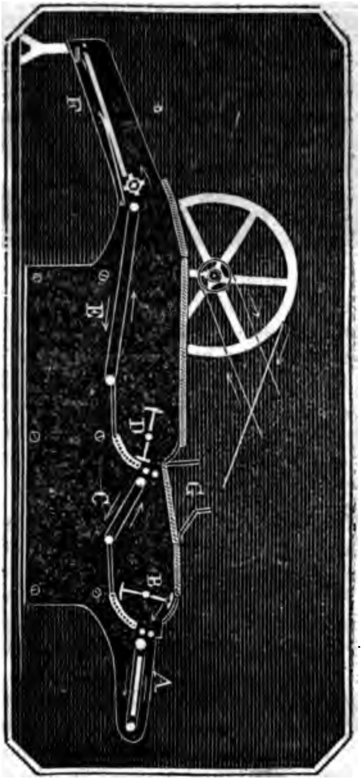


imagined more simple than this engine; yet, simple as it is, it has created the most important source of our national wealth. The services of Whitney to the United States are hardly less valuable than those of Watt to England; and it is a matter of national reproach, that these services were unrewarded, except by a grant from the State of South Carolina, and that far from bearing any relation to the immense wealth created by the machine.

274. The cotton, after being cleansed, is packed in bales, which are usually compressed, and the first operation in the manufacture consists in picking and opening it, for the purpose of separating any remaining seeds or other matter, and fitting it to be taken up by the next machine in the order of the process.

This operation was for a long time wholly performed by hand. It is now aided by machines, which go under the name of willows or winnows. The cotton thus picked and opened is placed upon a cloth, whose ends are united in such manner as to form an endless band, represented at A, which passes over two rollers, and carries the cotton forward to feed the blowing machine. This machine

Fig. 87.



has two rollers with grooved surfaces, which draw the cotton between them, and expose it to the action of a fly with two leaves or beaters B, which make 8 or 900 revolutions in a minute. These beaters, af-

ter having partially opened the cotton, throw it forward upon an inclined grating, whence it passes to a second band C, revolving on rollers, which carries it forward to a second pair of grooved rollers. These draw it in and deliver it to a second fly with beaters D, by which it is farther opened and thrown upon a second grating. During this process the cotton is exposed to a current of air produced by a revolving fan, by which the dust and impurities it contains are driven through the gratings, or up the chimney G. Finally, the cotton is carried forward from the gratings upon a third band E, until it passes out upon a frame or grating F, where it is collected in order to feed a second machine of similar character, called the batting or lapping machine. By this it is not only cleansed of any remaining impurities, but caused to form itself into a species of web called a bat. In order to form the bat, the cotton is delivered by the second band of cloth to a cylinder formed of wire gauze. The air is drawn from the inside of this cylinder by a revolving fan, placed in a flue provided for carrying off the dust; and the external air passing towards the cylinder in order to supply that displaced, presses the cotton against its surface, whence it is drawn off by a solid cylinder, and subjected, as it rolls itself upon it, to pressure from another cylinder.

275. The cotton bats are next carded. Before machinery was introduced, cotton was carded by hand. The cards used for this purpose were composed of wire, adapted to a sheet of leather, and furnished with a handle. Cards of similar character are now placed upon the surface of a cylinder. In order to their proper adaptation to this purpose, it is necessary that they be constructed with the greatest accuracy. The regularity and evenness of the thread

is in a great measure due to the regularity and perfection of the operation of carding. It would be impossible, without the aid of machinery, to give to the cards that degree of accuracy which is now aimed at. A machine has, in consequence, been invented by Whittemore, which manufactures cards with absolute accuracy. The leather is split by it with extreme precision into thin layers; the holes to receive the teeth are pierced in it with the utmost regularity; the wire is cut of exactly equal lengths, bent into a form comprising four angles, to which identical measures are given, and implanted in the leather.

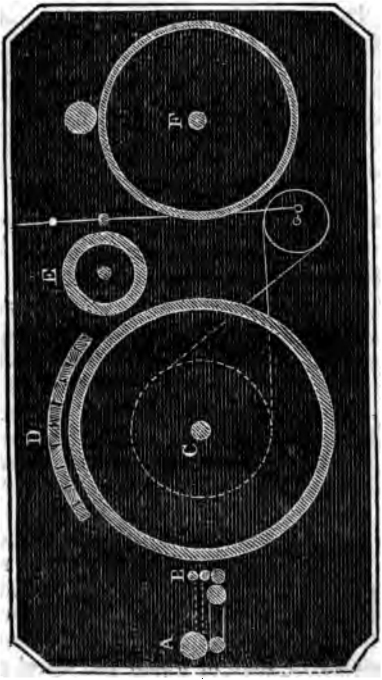
The carding is performed at two operations. In the first, the bat is laid upon a band of cloth, by which it is carried to two fluted rollers; these present it to a large cylinder, covered on the outside with cards. Over the upper part of this is a portion of a hollow cylinder, lined with cards, whose teeth are bent in a direction opposite to those of the former. Between these the fibres of the cotton are drawn, and arranged in parallel directions. The cotton is gradually carried forward until it reaches a cylinder called the doffer, which has cards upon it, arranged in the form of a spiral. The cotton is drawn off by the teeth of the cards on the doffer, and thence is removed by a comb, to which an oscillating motion in the vertical direction is given by a crank. By this arrangement of doffer and comb, a continuous band or *lap* is formed, which is wound upon a cylinder, and at the same time compressed by a roller.

The lap is cut off from time to time, and presented to the feeding rollers of the finishing cards. These have the same structure as the first, but the roll which is combed of the doffer, instead of being wound upon a cylinder and compressed, is received into a tin can.

The structure of the carding machine is represent*ed in fig. 88,* on page 278.

The cotton in bats is introduced at A upon a cloth, the ends of which are sewed together, and which is passed over two rollers. These rollers being set in motion by the engine, the cloth revolves and carries the cotton forward to two rollers at B, by which it is drawn within reach of the cards. These are arranged upon the surface of a large drum or cylinder C. Over this cylinder is a portion of a hollow cyl-

Fig. 88.



inder D, the inside of which is also covered with cards. After passing between the drum and the portion of the hollow cylinder, the cotton is caught upon a third set of cards, arranged upon a cylinder in the form of a screw. From this cylinder the cotton is removed in a continuous roll, by the comb F, and is wound upon the cylinder or doffer. The wheels, band, and crank by which motion is given to the comb, will be seen, and require no reference.

276. The materials, which are composed of filaments of such a character as to be capable of forming threads, were originally spun by hand, aided only by the rude apparatus called the distaff and spindle. Machines have, however, long been used to facilitate the operation, under the name of spinning-wheels. Of these there are two kinds, the great and the small wheel. These have served as the basis of the two principal engines, by which the force of the great natural agents has been substituted for human labour in spinning.

277. The great wheel is set in motion by the hand of the spinner, who, giving to it several impulses in rapid succession, causes a rotary motion, which the wheel retains for a time, in consequence of its inertia. By the revolution of the wheel, motion is given to a spindle. The material having been previously formed by cards into rolls, the end of one of these is rolled until it will be held upon the spindle, and, after the latter has received its motion, the spinner, holding the roll between the fingers, draws it in a direction oblique to the plane in which the wheel revolves. In this way the roll is drawn out, stretched, and, at the same time, twisted. Having thus drawn out a thread, the end of it is shifted until it comes into a *plane parallel* to that in which the wheel revolves.

When in this position, the revolution of the spindle coils the thread upon it. New rolls are attached by pressure to the unspun end of the former one, and the operation is repeated until as large a continuous thread as the spindle will receive, is wound upon it. This machine was principally employed in spinning wool of short staple, and is also suited to cotton, which may, however, be spun in the other manner.

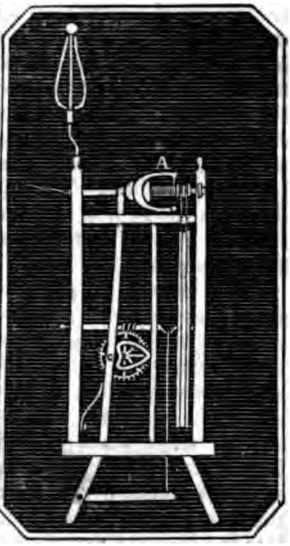
278. The small wheel is set in motion by a treadle, or step furnished with a hinge, to which an oscillating motion is given by the foot. The wheel has a crank on its axle, which is attached to the treadle by a connecting rod, and thus, like the fly-wheel of the steam-engine, acquires a continuous rotary motion. A rapid motion is given to a spindle by means of a band passing over the circumference of the wheel. The spindle of this wheel is not a simple rod of iron of the appropriate form, but has upon its end a part called the fly. This has the form represented by A in Fig. 89.

Upon the spindle is placed a bobbin, composed of two disks united by a hollow cylinder. The hollow is of such size as to slip readily over the spindle, and does not revolve with it, unless a force of intensity nearly sufficient to break the thread should assist the revolution. Upon one side of the fly are several short wires bent into the form of hooks. The matter to be spun being placed upon a distaff, which is mounted on the machine within reach of the spinner, a small portion is twisted by the fingers into the form of thread, drawn through an eye on the top of the spindle, thence through one of the hooks, and fastened to the bobbin. The wheel being set in motion, the fingers are still applied to unite and twist the filaments as they are drawn from the distaff by the revolution of the spindle, and the

thread is moved in succession from one hook to the next, in order that it may be wound uniformly upon the bobbin. By this instrument, prepared flax, combed wool, and cotton, the latter previously spun on the great wheel, may be formed into threads, which are more closely twisted than can be done by that instrument.

An improved spinning-wheel is represented in Fig. 89. In the upper part of the instrument is seen the distaff, on which the prepared material is wound; next below are the bobbin and fly; in the middle space, to the left, is the wheel over which the band that gives motion to the fly is passed; beneath all is the treadle, whence a rod proceeds to the crank on the axle of the wheel. The improvement consists in an endless screw on the axle of the wheel, which gives motion to a toothed wheel. On the same axle with the toothed wheel is a heart wheel or eccentric; this presses against a bar, which is pressed on the opposite side by a spring. The upper end of the bar is adjusted to the axle of the fly, which is caused by it to move to and fro, and thus to distribute the thread uniformly on the bobbin.

Fig. 89.



279. It will be obvious, that in the first of these instruments, the only part of the labour which required strength was the continual walking to and from the wheel; while in the latter no appreciable exertion of force was required. Hence, although very superior to the rude apparatus of distaff and spindle, they were very unprofitable applications of human strength. The great difficulty, either in combining such a number of spindles as might require the exertion of the whole strength, or driving them by some natural agent, which should render human labour unnecessary, consists in finding a substitute for the nice mechanism of the human hand in the small wheel, or to endow a machine with the intelligence by which, at an appropriate time in the motion of the great wheel, the act of twisting and drawing should be succeeded by one of mere stretching upon a thread already formed. It might almost seem that such qualities in machines could not be given except by a creative power, and yet they have been attained in the inventions of Arkwright, Hargraves, and Compton. Even these great inventors did little more towards the present state of the art, than to exhibit the principles in successful operation. Almost every day witnesses improvements in the plan of the subsidiary machinery, and the increasing perfection of the essential parts. In these improvements American ingenuity has borne its full share, and it has recently been stated by good authority,* that the most important machines used in this manufacture, for which patents are still in force in Great Britain, are the property of American inventors.

By the force of this ingenuity, the manufacture of

* Speech of Mr. Villiers in the House of Commons, February, 1839.

cotton in this country, which, little more than 20 years since, was utterly prostrated before the superior cheapness of that of Great Britain, has been increased until our goods not only compete with those of that country, in some cases to their actual exclusion, in markets where both are liable to equal fiscal charges, but actually rival them in the shops of Calcutta, where the British articles have the benefit of a protecting duty.

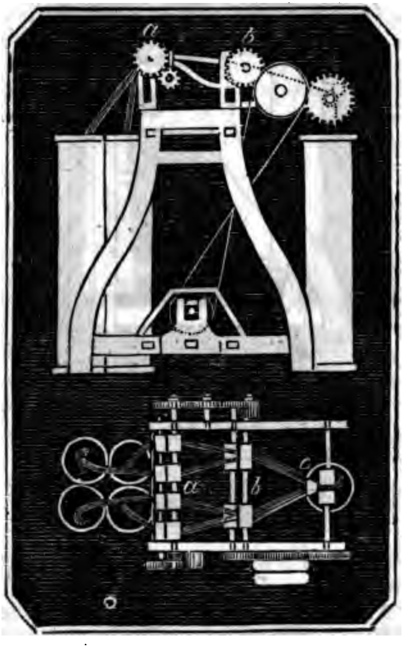
The quantity of cotton manufactured in the United States is now as great as was consumed in Great Britain in 1814; the Southern planters have found a new market equal to a fourth of their whole crop, and the Northern wheat-growers receive a price for their product not graduated by the cost of production, but by that of importation from foreign countries. However foreign to our subject, we cannot here help remarking, that in the face of these facts, the agriculturists of the United States are taught by political theorists to look with jealousy on the prosperity of their manufacturing brethren.

280. It would exceed our limits to enter into the detail of the processes in their present improved state. It is sufficient for our purpose to explain the principles on which the more important machines are founded.

The cotton having been carded into bands or slivers, which are received, as has been stated, in cans, is subjected to a process called drawing. By this several bands are united into one loosely spun thread, and have their length considerably increased. For this purpose, the ends of the several bands are each passed between two pairs of rollers, *a a* and *b b*. The lower roller of each pair is moved by machinery, the upper is set in motion by the friction which the band undergoes in passing it. The lower roll-

ers are made of iron and fluted, the upper roller is covered with leather. The second pair of rollers has a greater velocity than the first, and the band of cotton is thus increased in length. After passing the second pair of rollers, several of the bands are drawn together by passing them through a conical ring *c*, and are thence drawn in a body through a third pair of rollers, whence they are delivered into a tin can.

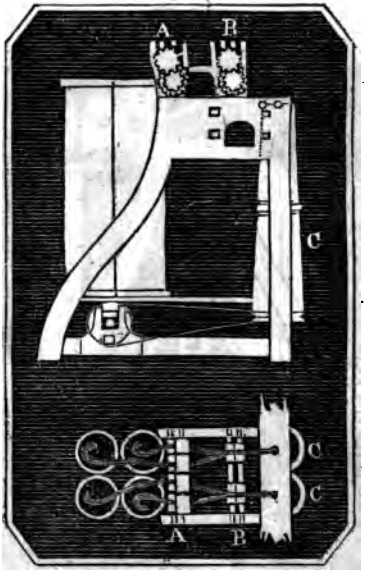
Fig. 90.



281. The process of roving, which follows next, is also performed by rollers, and in a similar manner, but the rovings are delivered into cans which have a revolving motion. This motion answers the double purpose of coiling the rovings neatly in the can, and giving them a slight twist.

The machine on which this is performed is represented in Fig. 91.

Fig. 91.



The slivers are drawn from the cans into which they were delivered by the drawing frame, by the rollers A. Thence they pass to the rollers B, where they are doubled. The doubled strands

then drop into the revolving cans C C, which are kept in motion by wheels and bands.

The operation of drawing is often repeated several times, in which case the rovings, instead of being received in revolving cans, are wound upon bobbins by means of a spindle and fly, as we shall describe under the head of throstle spinning. The only difference is, that in this case the apparatus is less delicate.

Instead of roving, this is sometimes called coarse bobbin and fly spinning.

282. At this stage the manufacture diverges into two different parts, known as mule and throstle spinning. By the former, a loosely-spun thread, used as the filling or *woof* in weaving, is obtained; by the second, one strong and tightly spun, known under the name of twist, and employed as warp or as sewing-thread.

283. Mule spinning is performed in two separate steps, on machines known as the mule and the stretching frame. In the latter, the bobbins or cans which have received the rovings are placed in a fixed frame, and drawn between three successive pairs of rollers; thence they pass to a spindle situated upon a moveable frame or carriage, whose wheels run upon a railway. At a particular stage of the motion, the drawing rollers cease to act, and the farther retreat of the carriage tends to stretch or extend the length of the roving which has already been delivered. At the same time, a greater degree of closeness is given to the thread, by making the spindles of the moveable frame revolve more rapidly, from which act the machine is called a double speeder. The carriage, having receded to the extent of the railroad, is returned towards the frame which contains the rollers, and at the same instant the position of the spindles is

changed, so that the thread may be wound upon them.

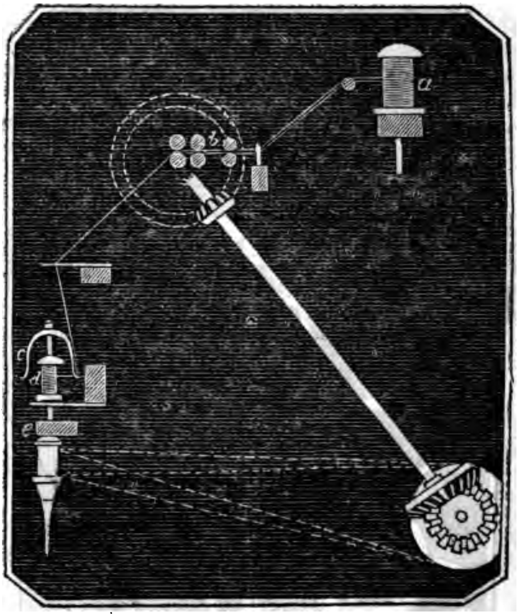
284. The mule differs from the stretching frame only in the fact, that the threads are delivered to the spindles during the whole receding motion of the carriage or mule, and that the double speed is omitted. The mule is fed from rovings, the stretching frame from the spindles which have been filled by the mule.

285. The motion of the carriages which bear the spindles was at first wholly performed by the labour of men. It is now, however, so far aided by the machinery, that the mule or stretching frame only requires to be returned by their exertion. The frames have, therefore, been gradually increased in size, until, from containing no more than one hundred and fifty spindles, they have been made in fine work to comprise eleven hundred. The operation of mule spinning is the only one which requires the strength of a full-grown man. All the other operations in cotton-spinning are superintended, rather than performed, by women and children. Each mule-spinner can manage two frames, which act alternately; but he requires the assistance of two or more persons, according to the number of spindles in the frames. The most important duty of these is to watch and piece the broken threads.

286. In throstle spinning the rovings are drawn out by successive pairs of rollers, in which, by increasing the velocity as before, they are extended in length. They are then wound upon a bobbin by means of a spindle and fly, imitated from the small wheel. The apparatus is represented in Fig. 92.

The thread is drawn from the bobbin *a*, through a series of rollers at *b*. It is thence carried through an opening in a plate, and bent downward until it is

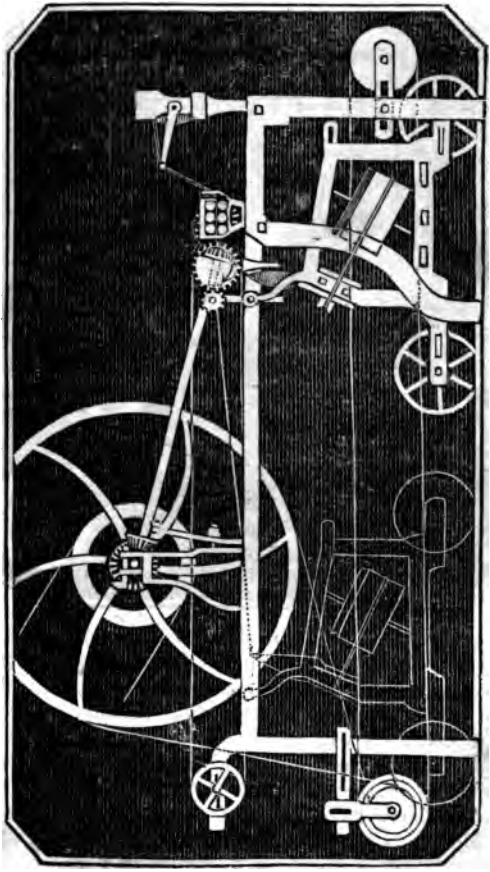
Fig. 92.



passed through an eye in the arm of the fly *c*, whence it proceeds to the bobbin *d*. In order to wind the thread uniformly on the latter, the rail *e*, on which the bobbin rests, is caused to move alternately up and down. It will be obvious that the winding of the thread on the bobbin will only take place in consequence of the difference between its velocity and that of the spindle.

Motion is given to the spindle and fly by bands.

Fig. 93.



and to the rollers by toothed wheels, which will be seen in the figure.

In later forms of the machine, one of the arms of the fly is made hollow, and the thread is passed through it.

In a recent throstle spinning machine, the fly has assumed the form of a hollow cylinder, and this is considered to be an important improvement.

287. According to the degree of fineness required for the threads, the operation of drawing is repeated two, three, four, or even as many as eight times. Even in coarse yarns, three successive drawings are often performed. In the first, six slivers are united into one; in the second, six of the first; and in the third, nine of those formed by the second drawing. The degree of extension of the rolls from the time they leave the cards is therefore

$$6 \times 6 \times 9 = 324.$$

When six successive drawings are employed, the extension may be represented by

$$8 \times 4 \times 7 \times 6 \times 6 \times 6 = 42{,}384.$$

In the finest spinning it is sometimes as much as 70,000. These degrees of fineness can only be obtained from Sea Island cotton.

288. The motion of the mules in the finer spinning is slower than in the coarser. Thus, in spinning thread denominated No. 40, from that number of hanks, each of 840 yards, being contained in a pound, the mule makes three motions in a minute, while in the higher numbers no more than one is performed in the same space of time.

289. The latest improvement which has taken place in this art is the introduction of the self-acting mule. The spinners of Great Britain having, under

false views of their interest, associated in trades unions, the owners of the manufacturing establishments were compelled to seek for such improvements in machinery as might render them independent of their workmen, and were successful. This machine is one of the most splendid triumphs of human ingenuity; and, so far from having interfered with the comforts of the spinners, it seems to have rather advanced their prosperity, by enabling them to free themselves from a thraldom imposed by the idle and dissipated members of their own body.

It happens, fortunately, that all improvements can be but slowly introduced, as they demand the sacrifice of the capital already invested in the older forms. Thus, while the combination was broken up, the means of occupation still remained in the old machinery.

The self-acting mule has been recently executed successfully in the United States, and will probably aid most materially in the extension of the cotton manufacture among us.

The common mule is represented in Fig. 93, on page 290.

290. The business of cotton spinning has been much decried as injurious to the health and morals of the persons employed in it. This, however, has been thoroughly disproved by accurate statistics in Europe, whereby it appears that the factory workmen are not only better paid, but have a better chance of life and higher moral character than the agricultural labourers. In that country it has certainly tended to elevate a debased population, and, therefore, it is not to be feared that in ours it will lower the standard of morals, while it will add materially to the comfort and independence of those who must be supported by the labour of their hands.

There can be no comparison between the comforts enjoyed by the females employed in manufacturing establishments, and those who accompany their families in seeking agricultural establishments in the new states of the West.

Flax Spinning.

291. Cotton adapts itself to manufacture by machinery with greater ease than any other of the materials whence threads can be spun. But, in spite of the difficulties which have opposed the spinning of wool, worsted, and flax by machinery, they have been overcome in a great degree. The general order and character of the methods is similar to that employed in the spinning of cotton, and the machinery used in the latter has served as the type of that which has succeeded in the other cases. Each different material, however, requires modifications in the structure and mode of working the apparatus, which, if they involve no important difference of principle, are, notwithstanding, absolutely essential to the success of the operation. The process by which coarse thread is spun from flax may be now considered to be nearly as complete as that used in spinning cotton; but the completion of this process does not promise to lead to results in any degree as valuable as those which have attended the cotton manufacture. The difference is owing to the great diversity in the preparation of the two substances. Cotton is fit for carding when it leaves the gin of Whitney, and is only subjected to intermediate processes in consequence of the compression it has undergone in packing, and the dirt which has entered it. These intermediate processes are simple and easy. Flax, on the other hand, requires a long and troublesome process to separate the fibres

from the matter with which it is combined, and must undergo several successive operations of greater difficulty than carding, before it can be spun.

292. The subsequent processes are drawing, roving, and spinning, as in the manufacture of cotton; but it is necessary that the flax be kept wet, which renders the manufacture disagreeable to the persons employed.

292. Flax has, until recently, been obtained from the plant by the process of rotting or retting. In this the bark and woody fibre of the plant are decomposed. This operation may be performed by exposure to air and moisture upon a meadow. It is then called dew-retting, but is more effectually accomplished by steeping the flax in ponds or artificial canals for 10 or 12 days. The water with which these are charged ought to be soft. Exposure on the grass for a few days is sufficient to complete the process.

This method is tedious and unwholesome, not only to those employed in it, but to those who reside in the neighbourhood. The flax also is liable to injury from the putrefaction being carried to too great an extent, while it may be, if the decomposition is not sufficiently advanced, but partially freed from the woody fibre. Various attempts have, in consequence, been made to destroy the impurities of the plant by machinery. None of these seem to have been successful as a preparation for the finer fabrics.

The decomposed woody matter is separated by a process called *breaking*. This was formerly performed entirely by hand, but is now effected by machinery. Breaking is performed by blunt iron teeth, fixed in pieces of wood, one set of which is fixed and the other moveable. When performed by machinery,

these may be arranged on cylinders, like the cards in the cotton carding machine. The separation is completed by *scutching*, which consists in beating the flax against a post, and with an instrument resembling a curry-comb.

The material, after being scutched, passes into the hands of the manufacturer. The first and preliminary part of the manufacture is called hackling. The hackle is composed of many teeth firmly fastened in a board. It appears probable that this operation might be accomplished by machinery.

Spinning of Woollen and Worsted.

294. The first operation which wool undergoes, as a preparation for spinning by machinery, is performed in a mill called a devil. This is composed of a cylinder about two and a half feet in diameter, and five rollers which lie above the cylinder. The cylinder and rollers are covered with teeth, which catch into each other, those of the cylinder interlocking with those of all the rollers, and the teeth of the several rollers interlocking with each other. The wool is charged through a door, in a case which covers the instrument, and is discharged by the centrifugal motion of the cylinder, at another door provided for the purpose.

295. The second operation is called scribbling, and is performed by cards placed upon cylinders, like those used in the cotton batting machine. Instead of a fixed concave cylinder covered with cards, as in that machine, the revolving cylinder is surrounded by pairs of small cylinders also covered with cards. The teeth of the opposite cards do not, as in the case of cotton, intersect each other, but are merely brought so near that a few fibres of the wool held by the teeth of one card can be caught and drawn out by

the teeth of the other. The wool being collected on a doffer, is stripped from it by a comb in a continuous fleece. The operation of scribbling is repeated three times.

These fleeces are then passed through the carding machine, which is constructed on the same principle as the cotton carding machine; but the doffer, instead of being entirely covered with teeth, is studded with strips of card about four inches in breadth. The wool is therefore stripped off in fine webs of that dimension. These fall into a trough of the shape of a half cylinder, and are formed into rolls by a fluted cylinder which revolves within the trough.

296. The rolls are next passed through a machine, called the slubbing billy. This is analogous to the roving machine of the cotton manufacture, but has rarely been successfully driven by any other prime mover except human strength. The subsequent processes are so like those employed in the cotton manufacture, that they do not require description, and, with the exception of the scribbling and carding machines, whose differences can be understood by a verbal description, the distinction between the machines used in spinning cotton and wool are so slight, that the same figures will serve to explain both. This has, however, regard only to the principle; for there is so great a distinction in the characters of the two materials, that a machine which has been constructed for spinning the one cannot be employed in the other.

297. Worsted is a variety of the woollen manufacture, in which a wool of long staple or fibre is used, and is treated in such a way that all the fibres shall be laid parallel. The stuff prepared from it, *therefore*, can have no nap or pile raised upon it.

Instead of carding, by which the longer fibres are broken up, an operation called combing is employed, in which the longer fibres are laid parallel, and the shorter fibres separated.

The comb is composed of two rows of pointed teeth made of tempered steel. Two combs are necessary, and they have handles attached when the process is to be performed by men. One of the combs is fixed with the teeth uppermost, on which the wool is placed, and thence drawn off upon the other comb. The combs require to be kept warm, as there is a particular temperature at which the process can be most conveniently and successfully conducted.

Combing by machinery has been found a difficult process, but has, at length, been successfully accomplished. The combs are placed on two wheels which revolve in opposite directions, so that the teeth of the opposite combs shall meet each other in their respective revolutions. One of the cylinders revolves on a fixed axis, the axle of the other has a reciprocating motion, by which it approaches and recedes from the fixed cylinder four times in each revolution.

The machine is made to register its own motions, and rings a bell when it ought to be stopped, in order to remove the combs which have become charged with wool.

These combs are then heated, and placed in another machine resembling in action the doffer of a cotton mill, by which the wool is drawn off in a continuous roll or sliver. This is received in a tin cylinder.

298. Hand-combed wool is formed by the hand into rolls of from five to seven feet in length. In applying these to the next machine, it is necessary to lay them on an inclined plane of plank, and to join

the ends by hand; while wool combed by the machine is drawn out from the cans.

299. The next process resembles in character the drawing and doubling of the cotton manufacture, and is performed on an apparatus called the breaking machine. The thread is formed by successive operations of drawing, spinning, and twisting, by methods and machines which have a general resemblance to those used in the cotton manufacture.

Silk Manufacture.

300. The production of silk promises to be an object of great importance in the United States. Our climate has a remarkable resemblance to that of China, the native country of the silkworm; and not only do the European and Asiatic varieties of the mulberry, which is the proper food of the silkworm, flourish from Connecticut, or even farther north, to Florida, but we have a native species, which, from late experiments, appears to be as well adapted to the purpose as any of the foreign.

301. The silkworm spins a web of the form of an egg, called a cocoon, in which it encloses itself. The insect must be killed by the heat of the sun or of an oven, or by the steam of boiling water. In this state the cocoon may be kept for a short time, but cannot be transported to any great distance. In order to convert the filaments of the cocoon into the raw silk, in which form it becomes an article of commerce, they must be drawn from the cocoons and formed into skeins. This operation is thus performed: the cocoons are thrown into a vessel of water, which is placed upon a charcoal fire, in order to maintain the liquid at an elevated temperature; the

warm water dissolves the gummy animal matter by which the thread of the cocoon is held together; a whisk or broom being then plunged into the water, such filaments as it may come in contact with adhere to it, and may be drawn out. A number, generally four, of these are taken, twisted together by the fingers, passed through an eye made of wire, and attached to the reel; this operation is repeated, and four more filaments twisted together are applied to another part of the reel, in such a manner that two threads may be reeled at a time; the reel is then turned by hand, requiring no greater force than the strength of a child, and a grown person attends to attach new filaments, as those of the first cocoon are expended.

The reel is so constructed as to have an alternating motion along its axis, through a space of about three inches, in order that the successive parts of the thread may not fall upon each other, in which case they might adhere by the gum which coats their surface. But a breadth of three inches is sufficient to allow the gum to become dry.

The reels are also moved by machinery, in establishments called filatures.

302. Raw silk thus formed into skeins is an important article of commerce, for in many of the countries which produce silk it is not manufactured farther. It would appear probable that it would for a long time be more profitable in this country to pursue this plan, for the labour required in the successive operations by which it is fitted for weaving is so great, in spite of the introduction of spinning machinery, that it can be performed in countries where human strength is less in demand on more advantageous terms than in the United States.

More profit will be derived from the preparation

of raw silk from the greater part of the cocoons, than in that of sewing-silk, to which it has principally been applied in the United States.

303. The first step in the manufacture of silk from its raw state is called winding. In it the skeins are replaced upon reels, and drawn thence upon bobbins. Winding was formerly performed by hand, on a machine carrying four bobbins, drawing from a like number of reels. Similar machines are now driven by water or a steam-engine. The great difficulty in this operation consists in the necessity of mending the threads which break, and in some of the silk-mills of England no fewer than one thousand children are employed in this operation alone.

304. The subsequent processes are doubling and throwing, or twisting. In the former, two, three, or more threads are laid together on the same bobbin. In the latter, these are wound upon another bobbin by means of a spindle and fly, as in the throstle spinning of the cotton manufacture.

Weaving and Finishing.

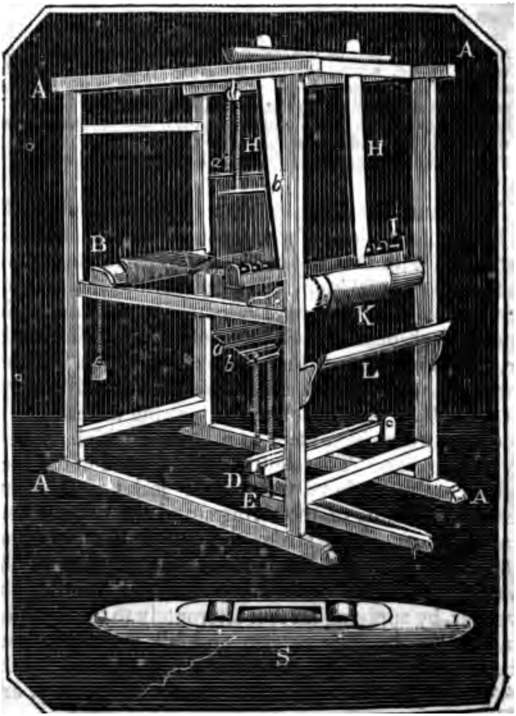
305. Weaving is performed upon an engine called the *loom*, which is among the most ancient of all machines. Woven cloth is composed of two sets of threads crossing each other at right angles. Those which extend lengthwise are called the *warp*, the cross threads are called the *woof* or filling. When the filling passes up and down between all the threads of the warp, the cloth has a uniform surface. By making it pass above or under more than one thread, before it changes to the opposite face of the cloth, a twill or diagonal edge may be raised, or patterns of any figure may be formed, as in the article known by the name of damask.

306. In order to prepare the warp for the loom,

each thread of which it is made up must be wound in a separate roll upon a beam. This was formerly a very laborious operation, but is now performed by a very ingenious machine of American invention.

The manner in which weaving is performed will be best understood from Fig. 94, which represents a loom of the most ancient and still most usual form.

Fig. 94.



A A A A. Wooden frame which encloses the loom.
B. Beam on which the warp is wound.
a a, *b b*. Heddles. These are two in number, and are each formed of two rods, *a* and *b*, united by threads. The threads are looped near the middle, and the threads of the warp are passed through these loops. The first thread is passed through the first loop on *a*, the second through the first loop on *b*, and thus alternately until all the warp has been used.
The heddles are suspended from pullies by cords reaching to the treadles D and E. By applying the foot to the treadles, one of the heddles is raised and the other is depressed. The alternate threads of the loop are thus separated, leaving an opening between them for the passage of the shuttle.
H H. *Batten.* This is a frame of wood which swings on hinges from the upper part of the frame; the latter is furnished below with a frame, which receives the *reed.* The threads of the warp are passed through the reed after they leave the heddles, and proceed thence to the cloth beam K.
The lower bar of the batten projects on each side beyond the vertical bars H H, and extends about an inch and a half in front of them, forming a *rail* or shelf on which the shuttle runs.
L. Seat.

The shuttle is represented on a larger scale at S. It is an oblong piece of wood, pointed at both ends, and furnished with two rollers, to cause it to run on its race with little friction. The ends of the shuttle-race are formed into troughs, I I, by means of thin boards, and in each of these is a piece of horn or thick leather, called a *pecker*. The peckers have holes in them, through each of which a short wire is passed to serve as a guide. Each pecker has a string fastened to it, and the two strings meet in a handle, which is held by the weaver. The shuttle being placed in the race between the peckers, the weaver jerks them alternately by means of the strings, and the two peckers are thus caused to strike the shuttle in succession, and throw it to and fro between the threads of the warp. Between each motion of the shuttle, the weaver, by applying his feet alternately to the treadles, causes the heddles to rise and fall, and thus closes the warp behind the thread which is carried by the shuttle. The batten is then drawn up forcibly, and completes the web.

307. The thread which is carried by the shuttle is wound on a small bobbin, which is fitted on a wire or spindle lying in a rectangular mortise formed in the upper surface of the shuttle.

308. In order to form a tweel or other pattern, more than one pair of heddles is used; and these are connected with treadles, which set them in motion when they are needed.

The heddles are sometimes so numerous as to require the aid of a boy to work them.

309. Before the addition of the peckers to the loom and the application of rollers to the shuttle, the latter was thrown from the hand of the weaver, provided the cloth were narrow; but in wide webs it was necessary for an assistant to be placed on each side of the loom, to recover and return the shuttle.

310. The motions even of the common loom are so complex, that it would appear difficult to substitute any other power for that of man. Looms to be driven by water or steam have, however, been introduced with success, under the name of the power loom. A front view of one of these is represented in Fig. 95, and a side view in Fig. 96, on page 304.

311. In order to finish cotton cloths, the pile or loose fibres are first singed off. This is performed by drawing the fabric slowly and steadily, by rollers moved by water or steam, over a cylinder kept at red heat.

The surface is then rendered smooth by calendering, which is an operation similar to that of mangling. A box containing heavy weights may be rolled over the cloth until it is perfectly smooth. Some fabrics are glazed by friction, after having coated the surface with a little wax.

Fig. 95.

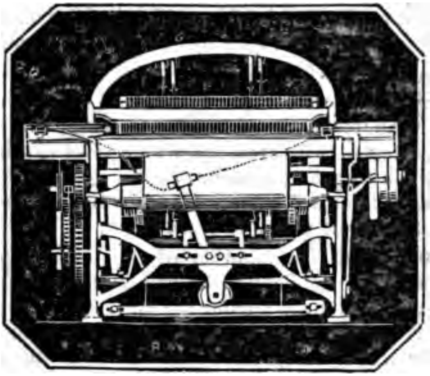
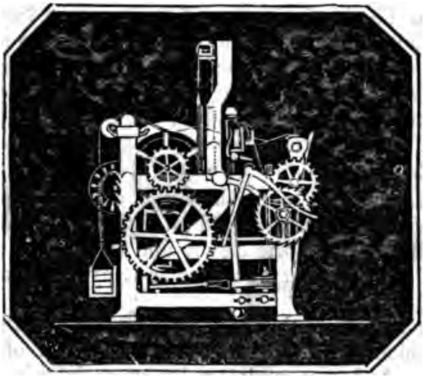


Fig. 96.



The best calenders are composed of rollers, and these have been slightly modified to answer the purpose of glazing also. When they have this form,

the cloth is passed through them with a continuous motion.

312. The finishing of woollen cloths begins with the process of fulling. This consists in agitating and exposing new surfaces to the action of water charged with fuller's earth or soap.

This operation is performed by mallets hung from a fixed axle, on which they have a reciprocating motion. The faces of the mallets are cut into steps, so as to double and bend the cloth in various directions.

313. After the fulling is completed, the cloth is stretched on vertical frames between tenter-hooks, in order that it may not shrink too much in drying. While in this position, any knots or uneven parts are removed from the surface of the cloth, and any holes which exist are darned up. The cloth is then beaten again for some hours in the fulling mill, for the purpose of causing the thread to adhere in the manner of felt. This operation is repeated several times, and the cloth thus becomes capable of receiving a fine surface, and is less pervious to water.

314. The next process is called dressing. This consists in raising the nap of the cloth. The only article which has been found to answer this purpose is the boll of a species of thistle called a *teazle*. A number of these were formerly arranged on frames, like those of the cards originally employed in the cotton manufacture. They are now arranged on a cylinder which is driven by machinery.

315. The nap thus raised is finally *shorn*. This was formerly done by hand, using large shears whose blades were fastened together by a steel spring. Various attempts have been made to shear cloth by machinery, and some of these have been

successful. In the most elegant of these methods the nap is cut by spiral knives arranged on the surface of a round rod or small cylinder, and the cloth is drawn forward by rollers.

Printing Machines.

316. The printing press in its original form was extremely rude, being no more than a common screw press with a set of ways, on which the form containing the type could be pushed beneath the point of pressure, and withdrawn between each motion of the *platen*, by which the paper was forcibly urged against the type. The great defect of this instrument, namely, that it required as many revolutions of the screw to raise the platen as had been employed in bringing it down, was remedied by a Dutch artist of the name of Blaew, who added a spring by which the platen was lifted the moment the action of the lever, by which the screw was moved, ceased. In this state the printing press continued until the beginning of the present century. From that time the alterations and improvements which have been introduced have been too numerous to allow us even to give a list. The most important of all these improvements, without which the application of any prime mover except the strength of man might perhaps have been impracticable, is in the mode of inking the types. This was formerly done by means of hollow balls of leather. It is now universally performed by means of a roller composed of a mixture of molasses and glue, which, after various trials, has been found better suited to the purpose than any other composition which has been tried.

317. *The* most perfect printing machine which

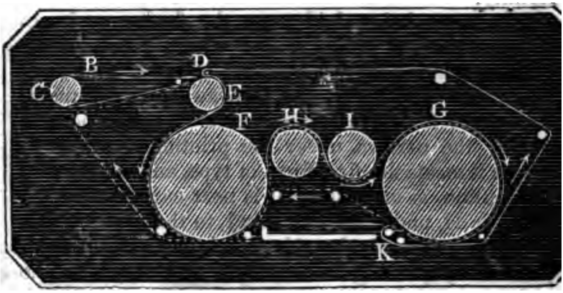
has yet been constructed is that by Applegarth and Cowper. It is planned to print both sides of the sheet before it leaves the machine, and turns out from 800 to 1000 sheets per hour, which is eight times as many as can be performed by the common press.

For newspaper printing, where one side of the sheet contains advertisements and other matter which may be printed in advance of the side which contains news, it is important to print as many copies as possible of one side of the sheet within a given time. Applegarth and Cowper have constructed one adapted to this object for the London "Times," and by means of it 4200 impressions have been obtained within the hour.

Printing machines are necessarily complicated. We cannot, therefore, undertake to describe one in all its details, but the general principles on which Applegarth and Cowper's double press acts will be understood from Fig. 97.

B is the feeder, which is composed of an end-

Fig. 97.



less band of linen cloth stretched over two rollers C and D. F and G are the printing cylin-

ders, made of iron, truly turned, and covered with a fine woollen cloth. Over these and the subsidiary cylinders E, H, and I, are stretched two systems of endless tapes, one of which is represented by a continuous, the other by a dotted line. Their direction and tension are maintained by a number of small rollers, whose sections appear in the figure. The tapes are so arranged in number and distance from each other as to fall upon the parts of the sheets which are to be left blank.

Immediately beneath this part of the apparatus is a long table, on which are placed the two forms of type, and which has an inking apparatus at each end. On the perfection of the latter the success of the process mainly depends. The table has an alternating motion, by which the forms are brought under the printing cylinders to meet the sheets, and withdrawn between the times of their passage under those cylinders. The feeder B has also a motion to and fro, by which the time at which the sheets succeed each other is regulated, and the motions of the table and of the rollers are adjusted in exact conformity.

The paper being laid upon the feeder as it retires, is carried in its return within reach of the point at which the two systems of tapes first meet upon the cylinder E, and is drawn between them. The paper is thence carried in the direction pointed out by the arrows, under the printing cylinder F, where it meets the first form of type, and receives an impression on one side. It is next carried over the cylinder H, under the cylinder I, to the printing cylinder G. To this the side which has already been printed by passing under F is now applied; the blank side of the sheet is therefore downward as it passes under the printing cylinder G, where it meets

the second form of type on the return of the table. After thus receiving an impression, the sheet is thrown out printed on both sides at K, where the two systems of types separate.

The machine may be set in motion by a band from the axle of the fly-wheel of a steam-engine. It requires so little force to turn it, that ten have been driven by an engine of five horse power. It may also be turned by hand. When propelled by steam it requires but two persons to attend it, one to lay the paper on the feeder, the other to receive the printed sheets.

XII.

ON MINING.

318. Mines are excavations made in the crust of the earth for the purpose of obtaining useful minerals. From this definition are to be excepted quarries of stone, and works intended for obtaining clay, sand, and other substances of little value. The term is, in fact, confined almost wholly to excavations intended to obtain the useful metals and coal.

319. The minerals which are the objects of mining, may be found: in beds in alluvial and diluvial soil, or mixed with the sand and gravel of these formations; in regular strata in secondary formations; and in veins traversing the more ancient rocks, whether stratified or not. The substances of value which are obtained in the first of these positions are the bog and meadow ores of iron, tin, and gold. Coal and ironstone are the most important minerals found in the second class of formations. All the useful metals are found in the third of these positions, but coal occurs only in the second.

320. Veins are fissures in rocks, extending generally to unknown depths, and which are filled up with minerals totally different from the rocks which they traverse. These minerals are sometimes wholly earthy, and the veins are, in consequence, barren. When they contain metallic ores, earthy matter may still form the greater part of the mass of the vein; in other cases, the metallic matter may be the body of the vein, and what earthy matter is present may *be adventitious*. In almost all cases veins are inclu-

ded in rocky envelopes, differing from the formation they traverse. So much of this as lies above the vein is called the roof, that which is beneath is called the floor.

Veins are of three descriptions, the flat, the pipe, and the rake vein. All of these are subject to contraction and enlargement, and the metallic matter they contain may vary materially in quantity in different parts of them. The richer parts, however, usually occur in strings or continuous masses, generally nearly parallel to each other, and having a constant direction and inclination. These appear to be properly the lodes, which most writers have confounded with the veins themselves. It is by this variety in thickness, and in being made up of lodes, the intervals between which may be barren, that the flat vein is to be distinguished from a bed or regular layer in a stratified formation. Flat veins have been in many instances traced to rake veins, and they appear to be, in fact, branches of such veins, which have spread themselves out horizontally, or nearly so, in the joints and weaker parts of the rock traversed by the rake vein. It may however happen, that convulsions, which have occurred subsequent to the formation of the vein, have separated the flat from the rake vein, whence it derived its origin.

Pipe veins are oblong, rounded masses, subject to the same law of contraction and enlargement as the rake and flat veins. They have probably been formed by the branches of a rake vein, and in the same manner as those which are flat, and have in some instances been traced to such a source.

321. To discover mines is attended with considerable difficulty, for geology as yet furnishes us with no certain rules for pointing out the positions in which they probably exist. On the other hand

geology gives positive and unequivocal indications, whence it will be at once known that mines cannot be found in given sites. But even in formations in which mines may possibly exist, the fact of their doing so can only be ascertained by actual research. Indications may sometimes be detected which may encourage the undertaking of such researches. These are fragments of ore in the diluvial soil, the decomposed rock, or the vegetable mould. Great care must be taken to distinguish these from pieces which have been transported from a distance by the action of water, for the source of the latter may lie at the distance of miles.

Minerals which occur in veins are never found in formations more recent than the older secondary; the formations which are next subsequent in date to the coal measures are the newest which are traversed by metalliferous veins, and it even appears that they do not exist in them when coal actually lies beneath. In some coal-fields, as in that of Durham, a few metalliferous veins have been found; but these are rather an exception to a general rule, and a coal formation is one of the least likely places to search for the more rare metals. It is otherwise with iron; this, in a form called iron-stone, which is an argillaceous carbonate of that metal, exists in many coal-fields, in layers coextensive with the coal itself. It is, therefore, an inquiry which is well worthy of attention, whether this ore, so valuable from its association with the fuel by which it is best smelted, cannot be found. Metallic veins may exist in all the formations of more ancient date than the coal measures, and are more likely to exist in a given part of them when it has been much disturbed, and the surface of the ground is rugged and mountainous. In the older stratified formations, magnetic iron, and pyrites,

often rich in gold, occur not only in veins, but as regularly stratified rocks of the formation. A full knowledge of these rules, in a more extended and precise form, will enable the geologist to determine whether a formation whence an ore is brought is such as to render the existence of a mine probable, or its working likely to be successful.

322. In the neighbourhood of mines which have been worked, the search for new bodies of mineral may be conducted with much less difficulty than in an unexplored region. Coal, and other minerals which occur in strata, have often, for considerable distances, the same inclination; and, even when there is a dislocation in the strata, these minerals still retain their relative position to the other rocks of the formation. The lodes of flat veins, and the mass of pipe veins, also maintain a direction and inclination which, for any considerable distance, is constant. The rake vein, if less regular than either when viewed within a limited space, is, notwithstanding, even more constant in its general direction and mean inclination. In consequence, when a vein has been opened at the surface, and worked until its general inclination or dip become known, it may be struck within a few feet of the calculated position by a vertical pit, commenced at the distance of many feet from the place where the vein crops out. So also veins have been traced in Cornwall for several miles, by following the same bearing of the compass, and excavations have not failed to strike them when not the slightest indication was visible at the surface. Coal may be found with even greater certainty; for the extent and limits of a coal-field can be ascertained with great precision, and anywhere within the space coal will be found, at a depth which may be

calculated from the inclination observed in other parts of the basin.

323. The place where a body of mineral matter appears at the surface, or even when it reaches the outer face of a rock covered with soil or disintegrated rock, is called its outcrop.

Where the outcrop of a vein or stratum is expected to exist, the search for it may be conducted by an open trench. This is intended for the purpose of removing the alluvial and diluvial deposites, with such parts of the rock formation as have been disintegrated by the action of the weather. The direction of such a trench must be across the probable direction of the vein or other mineral site. Nothing more can be done in this way than to determine whether a mineral exist or not in the position where its outcrop is suspected to be.

324. Whether the knowledge of the existence of a vein or stratum be gained in this or in any other way, its probable value, and the mode in which it may be best approached and entered, can only be determined by subterranean works, unless the necessary facts can be inferred from mines worked in the neighbourhood.

With these works in the vein or bed itself, accurate geometric surveys, both of the horizontal dimensions and level, must be combined, and all the subterranean works must also be carefully measured, as well in their lineal dimensions and direction, as in their inclination and change of level. Records and maps of such surveys must be carefully preserved, for it is only by reference to them that any true knowledge of the state of the works can be obtained, or any sure plans laid down for its subsequent working.

325. Subterranean works of research may be either galleries or shafts. The former are passages cut in a position nearly horizontal. The latter are pits, and may be either vertical or inclined. Galleries may be either directed along the body of a vein or layer, or may be nearly perpendicular to that direction. Inclined shafts will follow the inclination of the vein downward, while those which are vertical may pass through the rocks in which it lies.

326. When the rocks which overlie the mineral are not too hard, the search for it may be pursued by boring. The instrument usually employed is nothing more than a large auger, the shank of which is composed of a number of separate pieces, which are joined to each other in proportion as the depth increases. The joint is formed by a square mortise, into which a square head drops ; the two pieces are then keyed together. The auger is provided with a number of cutters of different forms, each adapted to some particular description of soil.

327. Mines are sometimes worked open to the day ; this is usually the case with quarries of stone, and always with alluvial and diluvial ores of iron, with clay and sand, and with turf. In the same way are worked the greater part of the lignites, some beds of coal, the iron of Elba, and various metallic minerals in Sweden and Norway. In this country, the great beds of coal which are found at Mauchunck have hitherto been entirely worked in this manner, and the same is the case with the valuable bed of hematite at Salisbury, Conn.

This mode of working can only be profitably performed when the mineral lies nearly parallel to the surface, and the whole of the cover can be easily removed.

328. Subterranean works alone are generally applicable to the greater part of mineral sites. Such, however, is the difference in the manner of their occurrence, that methods of very different character must be adopted, corresponding to the great variety of circumstances in which valuable minerals occur. Minerals may occur in positions which can be classed under five distinct heads.

1. Veins or beds nearly vertical, or having an inclination of more than 45°, and whose average thickness does not exceed 6 feet.

2. Beds whose thickness is not more than 6 feet, and which are horizontal, or nearly so.

3. Beds of great thickness and small inclination.

4. Veins or beds nearly vertical, and of great thickness.

5. Masses whose dimensions are considerable in every direction. These may either be portions of a very thick bed, or a space the whole of which must be extracted in consequence of the number of veins which intersect it.

329. The working of mines includes two very distinct classes of operations: those which are preparatory, and those by which the mineral is removed. The preparatory works consist: of galleries or shafts, by which the miner reaches the fittest place for beginning to extract the mineral; of similar works, by which the site of the mineral is reconnoitred; of passages of either description, for the drainage of water, for the circulation of air, and the transportation of the minerals after they are separated from the vein.

When a vein or bed is situated on a hill, and its direction is nearly perpendicular to the face of the height, and crops out at its surface, a gallery should be opened in the outcrop at the lowest accessible

position. This will serve the double purpose of draining the mine, and of exploring the nature and value of the mineral, in the direction of the vein itself. Farther researches may be carried on by pushing galleries or inclined shafts upward from this main gallery, and uniting them from time to time by cross galleries. In all works of this latter description, it is important that they be laid out with the greatest regularity, and carried on in lines parallel and perpendicular to each other.

When the vein is situated in a hill, and is nearly parallel to its face, a gallery is driven in such manner as to cut the vein in the most direct manner, and at the lowest accessible level. A cross gallery is then cut to the right and left in the vein itself, and works similar to those last mentioned in the former case are pushed upward in the vein.

When a bed or vein is much inclined to the horizon, a vertical shaft should be sunk, beginning at some distance from the vein, on the side of its roof, and be carried down until it cuts the vein. If, however, the roof is of such a nature that it is to be feared that it may not stand, the shaft may be sunk on the side of the floor, and a horizontal gallery driven towards the vein, until it is cut from the bottom of the shaft. In some cases, an inclined shaft may be sunk in the vein itself. This will be longer than the vertical shaft, will be less solid, and more costly in its structure; but it will sometimes cut through ores or minerals of considerable value. It also serves to explore the vein. On the other hand, the part of the vein through which it passes cannot be touched without danger; and more ore will thus be lost than is extracted by the shaft itself.

If the vein or bed be nearly horizontal, and lie

deep in the ground, the preparatory work must also be a vertical shaft.

Were it not for the expense, it would be better, in both these cases, to sink two shafts, in order to obtain a circulation of air. These must be united by a gallery cut in the vein or bed.

When two veins cross each other, the shaft ought to be sunk in such manner as to cut them at their common intersection.

330. After these preparatory works are finished and those of extraction are commenced, it is still necessary to carry on works of research, in order that the working of the mine may not be suddenly checked. These works of research consist in galleries crossing each other at right angles when the inclination is small, or in inclined pits and horizontal galleries when it is great. They are to be cut in the vein itself, occupying its whole thickness, and are extended into the wall and roof, or even into the adjacent rock, when the vein is thin. These galleries or shafts must be not more than from 80 to 150 feet apart. In some cases the want of fresh air will make it necessary to cut galleries at less distances than these from each other.

331. The spaces into which the vein or layer is divided are then to be taken out. This is done by working in a series of steps when the inclination is great, or by galleries crossing each other at smaller intervals when the bed or vein is nearly horizontal. In the latter case, no more of the vein is left than pillars of sufficient strength to support the roof. When the mineral is of no great value, these pillars are sometimes lost altogether; in other cases they are removed, and replaced by wooden posts. When the whole of the mineral is removed, these posts are

sometimes taken out and the roof allowed to crush in. This operation is often dangerous, but is frequently absolutely necessary, to maintain the value of the mine, and provide for its being worked with ease.

Of all mines, whether in veins or beds, those which have a thickness of from five to seven feet are worked with the greatest ease. When they are much inclined, the whole of the vein or bed may be taken out by working in the method of steps, which has been already referred to. This method may be performed either by beginning at the top or at the bottom of the mass to be excavated. In the former case, a miner begins at the side of a shaft, about six feet below a former working or the upper part of the vein, and excavates a space in the vein seven feet in height. As he proceeds, he forms a platform behind him of timber and plank, on which he piles the refuse matter of his excavation. As soon as he has proceeded to the distance of seven or eight feet from the shaft, a second miner begins on the part of the vein immediately beneath that which the first has extracted, and proceeds in the same way. In the meantime, the first miner continues his labours. As soon as the second miner has proceeded to the same distance of from seven to eight feet from the shaft, a third miner is set to work beneath him, and so on, until the whole space on the side of the shaft between two horizontal galleries is occupied.

In the second case, a horizontal gallery, well supported with timber, is carried forward in the vein from the bottom of a shaft. The first miner begins to work on the roof of this gallery, and throws the rubbish on the timber which covers it. This forms an inclined plane, on which, after he has proceeded seven or eight feet, a second miner may be set

work behind him, and so on until the whole space is occupied. This method is applicable in veins which are as thin as eighteen inches.

Veins of considerable inclination and great thickness are pierced by means of horizontal galleries; and it is necessary, unless when timber is very abundant, to leave floors and partitions of the mineral between the several galleries. The mineral thus left is wholly lost.

332. In very thick beds, the work is conducted by dividing it into stages of about six feet in thickness. For this purpose advantage is taken, if possible, of natural partings, which often exist in the bed. The working is begun in the lower stage, and is carried on by a series of galleries and rooms crossing each other at right angles, leaving pillars in their intersections. In laying out the workings of the second and upper stages, the greatest care must be taken that their several galleries and rooms lie immediately above those of the lower stages, so that the pillars may in fact be continuous from the floor to the roof of the bed.

If there be any quantity of refuse matter, it must be used to fill up the galleries of the lower stages, and in this case new galleries may be cut in the pillars, by which an additional quantity of mineral can be taken out. The upper stage, if the refuse matter be sufficient to fill up all the lower galleries, may be treated like a thin bed, and the whole of the mineral extracted.

In very thin beds or flat veins, the main galleries by which the *country* is explored must be cut into the roof, and made high enough to permit the free motion of the workmen, and of the vehicles by which the ore is removed. The intervening portions of the layer are worked by men lying on their sides.

When masses of considerable thickness exist at no great depth, shafts may be sunk until they cut the mineral; these are enlarged in every direction into the form of a cone or conoid, until there begins to be danger that the rock will no longer support itself. The shaft is then abandoned and a new one commenced.

The parts of the mine nearest to the point where the entrance gallery or main shaft enters it, ought not to be worked until all those which are more distant have been exhausted.

333. The dangers to which miners are exposed are the falling of the rocks, which are always divided by joints or fissures; the crushing of loose earth or decomposed rock, and particularly of quicksand; accumulations of water, and collections of foul air.

334. The galleries and shafts may be cut in strong and firm rock; in this case they will need little or no support. When this is not the case, shafts require to be surrounded by a kerb. This may be composed of timber or of masonry. In the former case the shaft must be rectangular, in the latter case it is circular or elliptical.

Galleries are sustained, when necessary, by a series of frames, each composed of three pieces of timber. These frames are usually about three feet apart, and if the ground on the sides be bad, the spaces between them are filled up with short bars of wood. The roof of the gallery is formed in the same way.

The spaces between the galleries whence ore is extracted are supported by posts, unless the working itself furnishes a sufficient quantity of rubbish to form pillars wherewith to hold up the roof.

335. Whenever it is practicable, mines should be drained of water by means of a horizontal gallery. That which has been spoken of among the works of preparation will often answer the purpose. In this case it is to be divided into two parts by a horizontal floor, beneath which the water may run, and on which the mineral may be carried out. The greatest slope of a gallery of drainage ought not to exceed $\frac{1}{400}$th.

When the part of the vein which lies above the gallery is exhausted, it becomes necessary to work the mine beneath that level. In this case artificial means of drainage must be employed, and it was to meet an instance of this sort that the machine of Schemnitz, described in § 209, was invented. On the Continent of Europe and in Spanish America, the law provides for a division of the expense of a gallery of drainage among those who are benefited by it. Under the protection of this law, a gallery of several miles in length has been constructed in Saxony. This gallery passes at a depth of 900 feet beneath a village, and took 23 years to construct.

In sinking shafts, and in drainage of no great depth, horse power may be used. The best arrangement for the use of this kind of force is called the *whim*. It is a capstan, to the bar of which two horses are harnessed. A rope is wound around the barrel of this windlass, and has a bucket at each end, so that as one bucket is drawn up, the other descends. The horse-path is so wide that the horses can be turned around for the purpose of reversing their motion. The best buckets for this purpose are made of two hides sewn or riveted together. The tails form a pipe or passage through which the water enters when the bucket descends into the well at the bottom of the shaft. This pipe is then

lifted and hooked to the top of the bucket. When it reaches the top of the shaft, the pipe is unhooked, and the water is discharged through it.

These buckets were originally employed in Mexico, and were made of raw hides; in those which have been used in this country, the hides are tanned, by which they are rendered much more durable.

The most perfect of all modes of drainage is the forcing pump moved by a steam-engine. When the depth exceeds 130 feet, two stages of pumps are necessary, and an additional stage for every 130 feet in addition. In sinking a shaft, the pump may be used almost from the beginning of the work. It is, for this purpose, fastened to a wooden frame, the lower end of which rests on the bottom of the excavation.

The single-acting engine, working expansively, has been preferred for working the pumps of mines; but double-acting condensing, and high-pressure engines have also been successfully employed. Whatever be the mode in which water is raised in a vertical shaft, it is necessary that the excavation be continued for some feet below the workings, in order to form a well for the collection of the water of the mine.

336. The air of mines is rendered foul by the breath of the workmen, the combustion of their lights, and the decomposition of the wood which is employed in supporting the galleries, &c. Carbonic acid in addition is often evolved by the waters, and carburetted and sulphuretted hydrogen are given out from beds of coal. Mines of metals often give out arsenical vapours, and those of mercury the vapour of that metal.

Not only are these gases and vapours injurious, and even destructive when breathed, but the hydro-

gen forms with atmospheric air an explosive compound, which, if entered by a light, produces the most disastrous effects.

For these reasons, it is of the utmost importance that mines be well ventilated. This should be done wherever it is possible by natural currents of air, but it is often necessary to resort to artificial means.

The principle of natural ventilation depends upon the fact that there is generally a difference between the temperature of mines and that of the external air. In winter the mines are always warmer than the atmosphere, and in summer they are often colder. So long as the difference in temperature is considerable, it is only necessary that the mine should have two openings at different levels, and the external air will enter by the one and escape by the other. The works of the mine must be formed, by means of partitions of plank, crossing and closing galleries into a single series of passages, by which the air will circulate backward and forward from the time it enters the mine until it reaches the place of discharge. In these partitions doors must often be placed, in order to permit the passage of the workmen and of the matter extracted from the mine. It will be absolutely necessary to keep these doors open for the shortest possible time, for they admit a more direct passage for the air, and thus all the ventilation of the more distant galleries will be intercepted.

Even a single opening, whether it be a gallery or a shaft, may serve to ventilate a mine. In the case of a gallery, a short shaft may be sunk at no great distance from its entrance, reaching from the gallery to the surface of the ground. The gallery is then to be divided into two parts by a horizontal partition; the upper part communicates with the shaft,

and the two parts communicate only at the farthest extremity of the gallery. The water which runs in the gallery will aid in causing a current of air.

When there is no more than one shaft, it must be divided into two parts by a vertical partition of plank, carried down to the very bottom, or, at least, beneath the surface of the water in the well. The galleries on each side of the shaft communicate with one of its two divisions, and the same arrangement of partitions is made as in the case of two galleries, so as to form one continuous passage to and fro, by which the air that descends through one of the compartments of the shaft may circulate throughout the whole mine before it reaches the other. The importance of making the partitions tight, and of keeping any doors which may be left in them as much closed as possible, is even more important in this case than in that of galleries.

It is to the opening of a door in a mine arranged for ventilation in this way, that the fatal explosion at Blackheath, in Virginia, is to be attributed. By this explosion 60 workmen lost their lives.

The mere agitation produced by the working of the pumps in one of the compartments of the shaft is often sufficient to change the temperature of the air in it and cause a current, but it is more safe to place a chimney in communication with the smaller compartment, by which the advantage of a difference of level in the openings will be attained.

A more secure ventilation will be effected in this case by the artificial means of heat. A fire may be lighted in one of the compartments of the shaft at some distance from the bottom, and the chimney in this case will be unnecessary. When there is a chimney, a fire may be built in a furnace placed between it and [illegible] the compartments of the shaft.

This furnace must have no other openings than those by which it communicates with the shaft and chimney, except the door for feeding the fire, and this should be only opened when the fuel is thrown in.

Until the mine is sufficiently opened to permit its being arranged in a system of passages for ventilation, and when the difference in the temperature of the internal and external air is not sufficient, other artificial means may be resorted to. Thus fresh air may be forced in by bellows or blowing machines of various descriptions. In this way, however, the fresh air is merely mixed with the foul, and the ventilation is never complete. It is otherwise when the foul air is pumped from the mine by similar machines working in an opposite direction. The simplest machine which has ever been constructed for this purpose is formed of one tub inverted within another, filled with water. A pipe passes through the bottom of the latter, rising above the surface of the water it contains, and is extended to the most distant point of the mine, or to the discharging end of the series of passages. The first tub has upon its bottom, which, as it is inverted, is uppermost, a valve opening upward. The machine is worked by attaching the first tub to the pumping engine, by which it is alternately raised and lowered.

In coal-mines the danger of explosion might be avoided altogether by the use of the safety-lamp of Davy, were it not that the wire gauze with which it is covered is liable to be torn, and it is hardly possible to compel workmen to pay sufficient attention to keep them in proper order. When there is even a small rent in them, they are as dangerous as an uncovered light, and with this addition, that confidence *is reposed* in them.

337. We have thus completed an attempt to give, in a condensed form, a view of many of the more important applications of the science of mechanics to industry. One of great moment has been purposely omitted, namely, the principles of architecture and the practice of building. These are of sufficient moment to require a treatise to themselves, and materials for such a work are in preparation.

The view we have given of the application of prime movers, and particularly of the steam-engine, is calculated to give us an exalted opinion of the powers of the human mind, in its influence not only over inert matter, but over the elements themselves. Still, however lofty may be the estimate we thus form of the achievements of human genius, it will be seen that all which the utmost exertion of skill or talent has been able to effect, or, indeed, can ever accomplish, is to bring into action powers and agents, provided not merely for our own use, but for the fulfilment of the most important purposes in the creation. We not only bridle the wild steed, and compel him to bear burdens or draw loads, but we intercept the waters in their return course to the ocean, catch upon sails the whirling currents of the atmosphere, confine the imponderable element of heat, and compel it to expand an inert and inactive fluid into vapour. Mighty as are the effects that are thus produced, they are no more than applications of forces to whose source and origin we cannot approach; and man in the exertion of his highest powers over matter, is only rendered the more sensible of his dependance upon the Creator not only of his own frame, but of the natural agents, by the use of which he is enabled to accomplish so many important objects.